GEM/THGEM applications – updates for Digital Hadron Calorimetry and Tracking

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LC 2013, DESY, Hamburg, May 2013

Outline

Three topics:

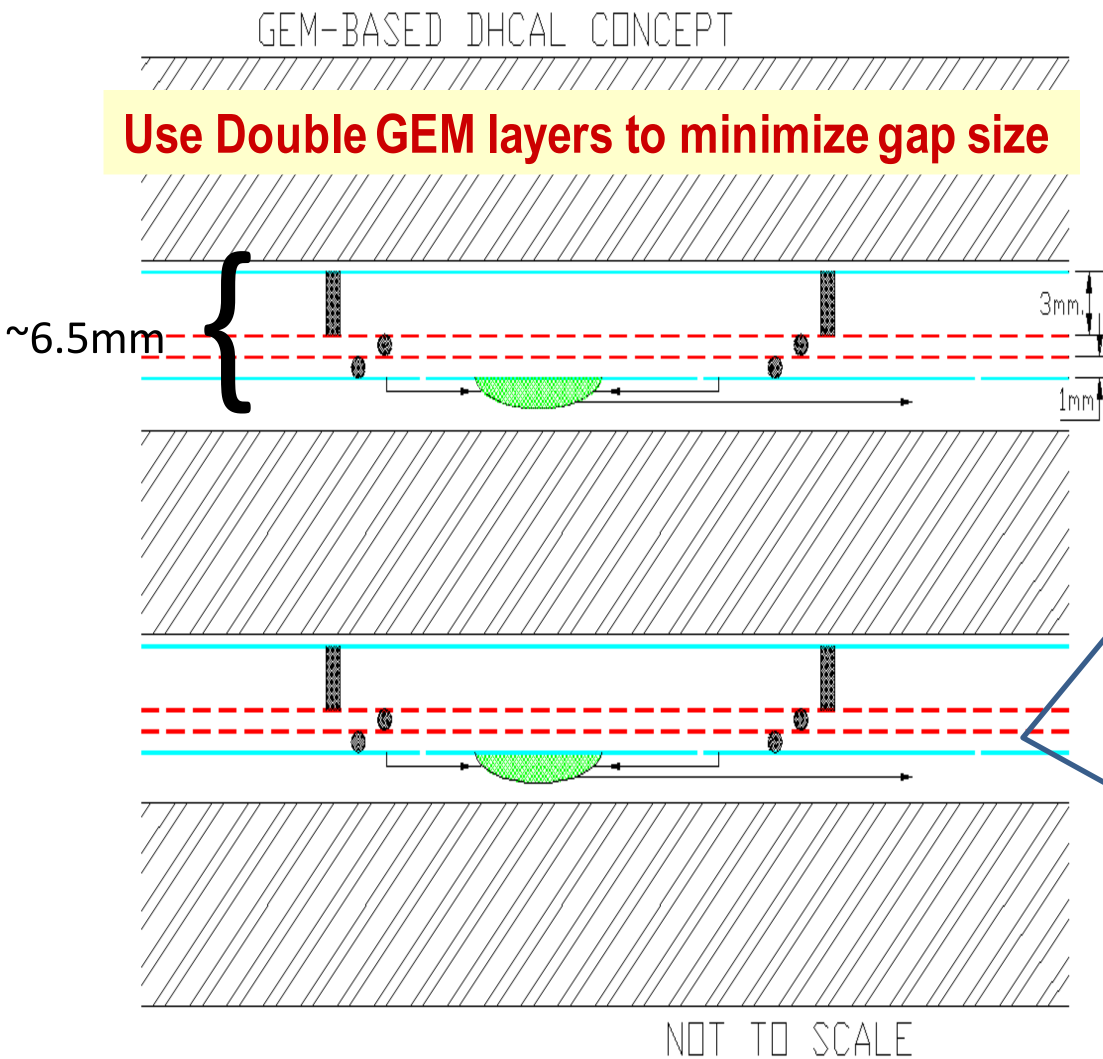
- GEM/DHCAL status

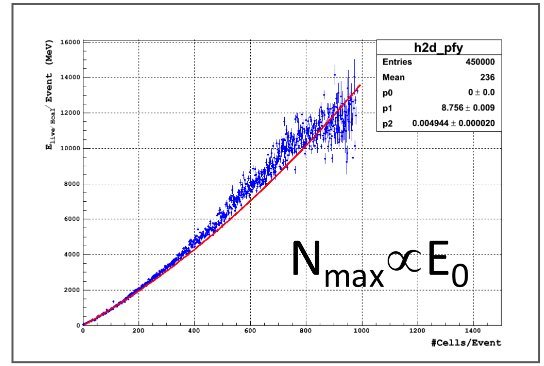
- THGEM developments/testbeam

- Tracking application of large GEM chambers

GEM-based Digital Calorimeter Concept

Use Double GEM layers to minimize gap size





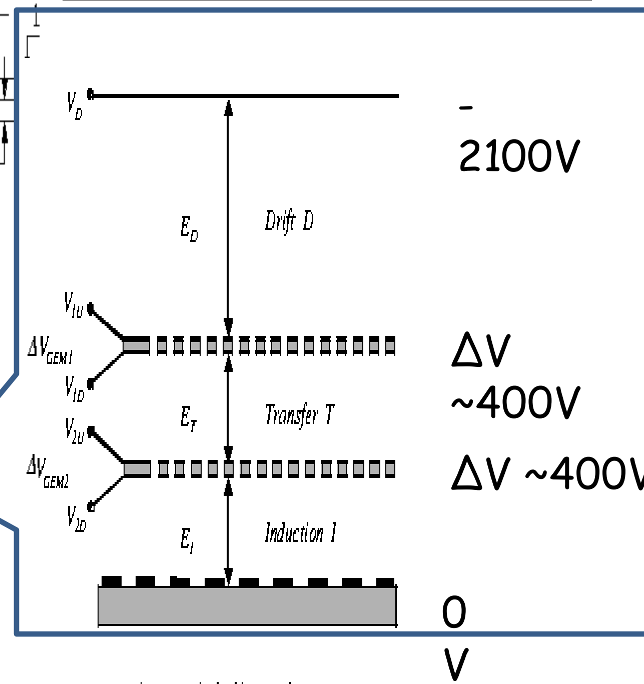
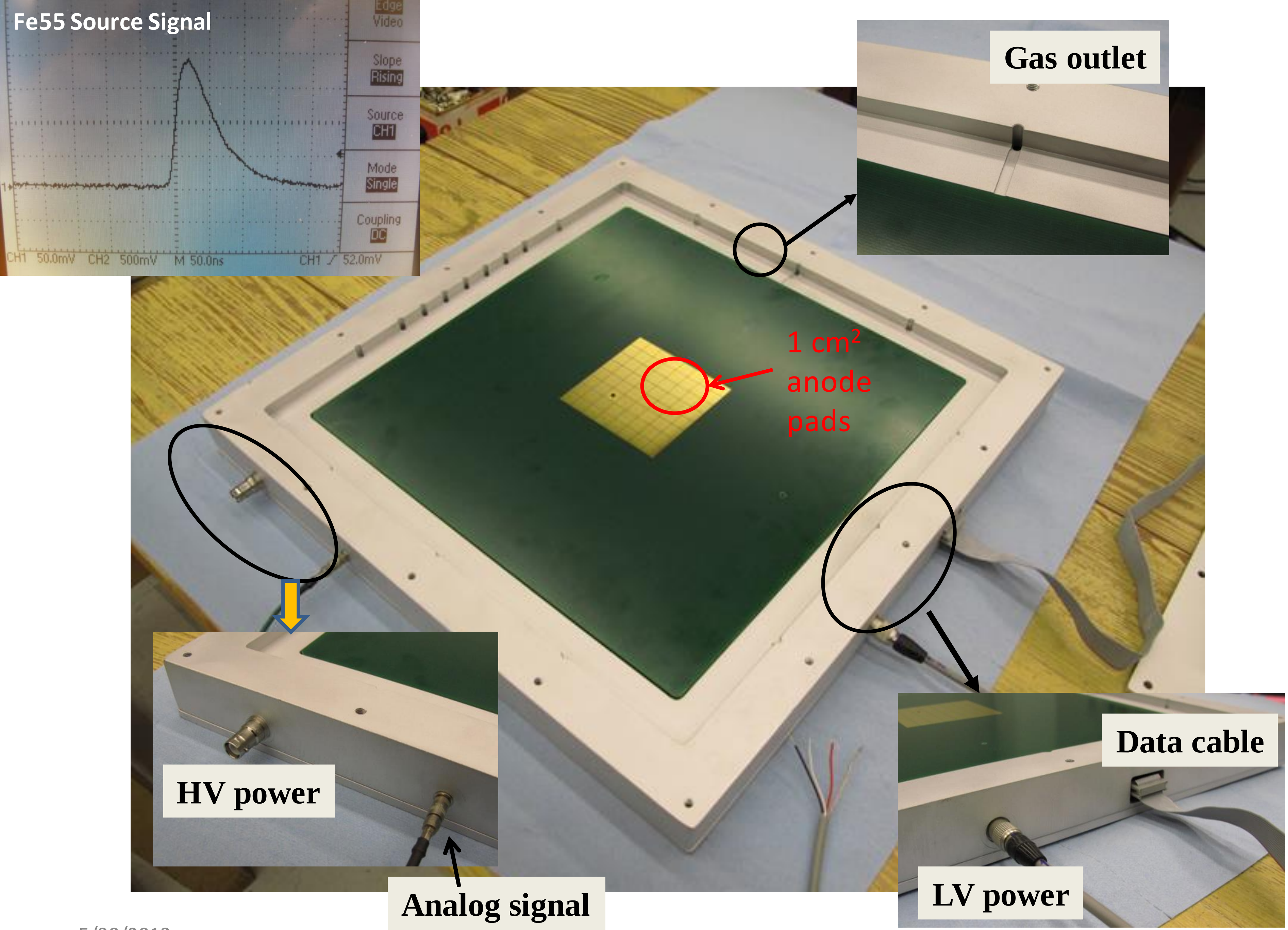
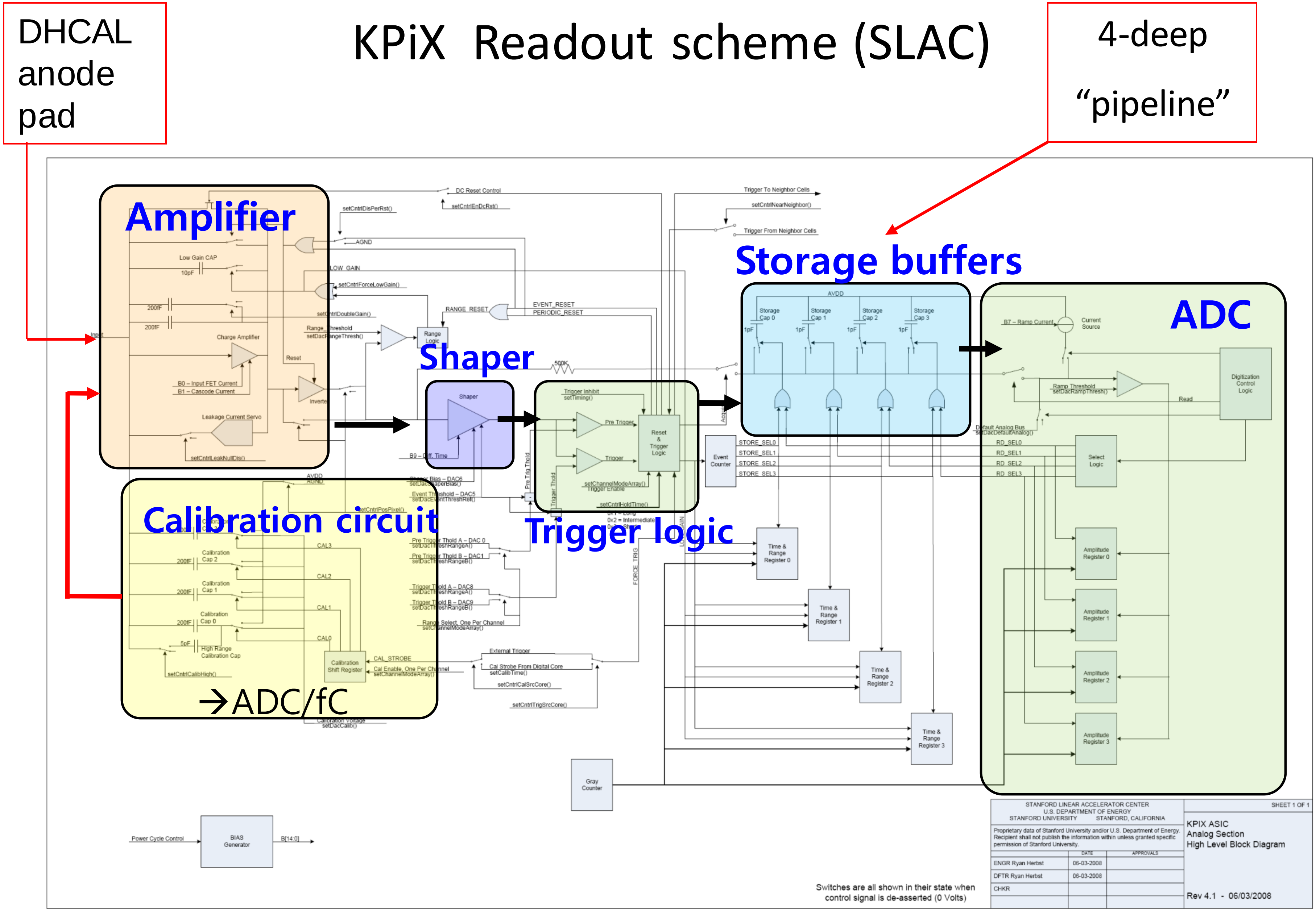


Fig. 1: Schematics of a double-GEM detector.


Fe55 Source Signal
Slope Rising
Source CH1
Mode Single
Coupling DC
CH1 50.0mV CH2 500mV M 50.0ns CH1 ∕ 52.0mV
Gas outlet
1 cm^2 anode pads
HV power
Analog signal
Data cable
LV power

KPiX Readout scheme (SLAC)



GEM Integration with DCAL Chip

Goal: Enable readout of GEM/DHCAL planes via DCAL as the ultimate readout electronics of a $1m^3$ stack ➔ Chip has been well tested with RPC DHCAL stack (ANL)

- Use DCAL in high-gain mode to establish MIP signals.
- Determined noise level for DCAL/GEM combination
- Determined operating threshold(s) for DCAL
- Determine efficiency/uniformity/multiplicity for GEM/DCAL
- Understand issues of using DCAL readout system with $1m^2$ GEM/DHCAL planes in a test beam stack.

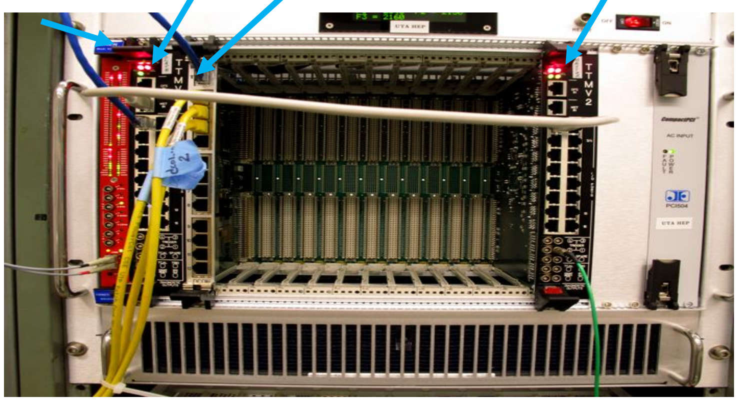
PCI interface (Optical link)

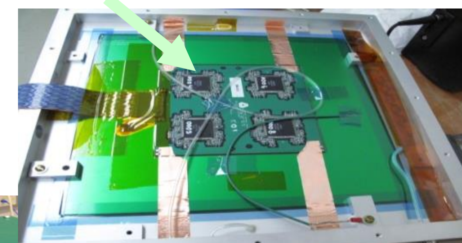
Trigger/Timing module (Slave)

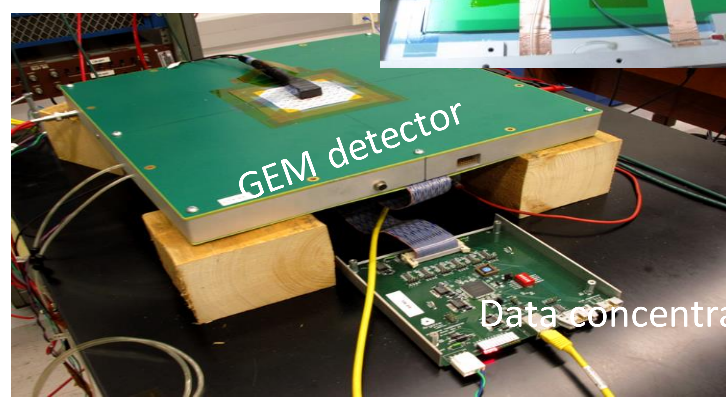
Data collector

Trigger/Timing module (Master)

20cmx20cmD CAL board

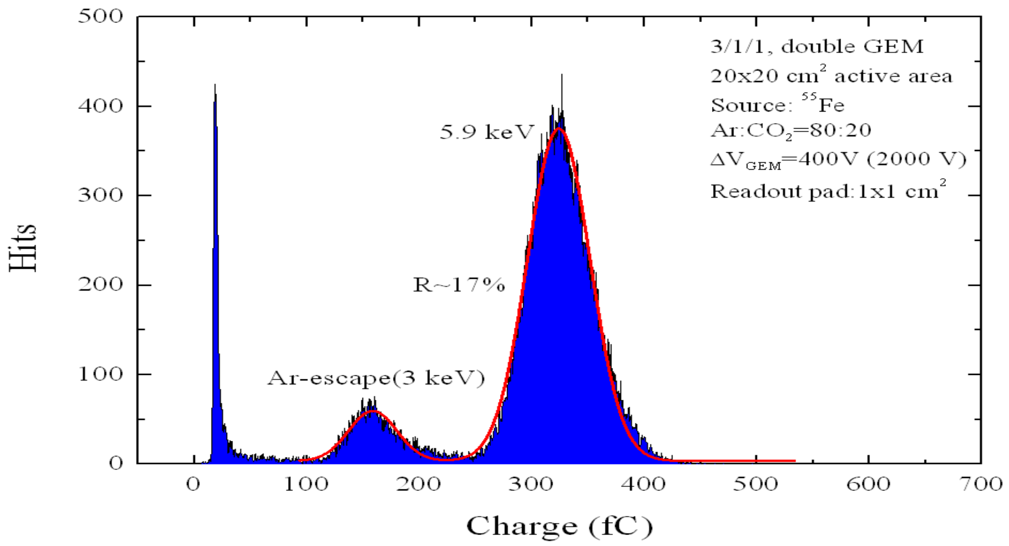


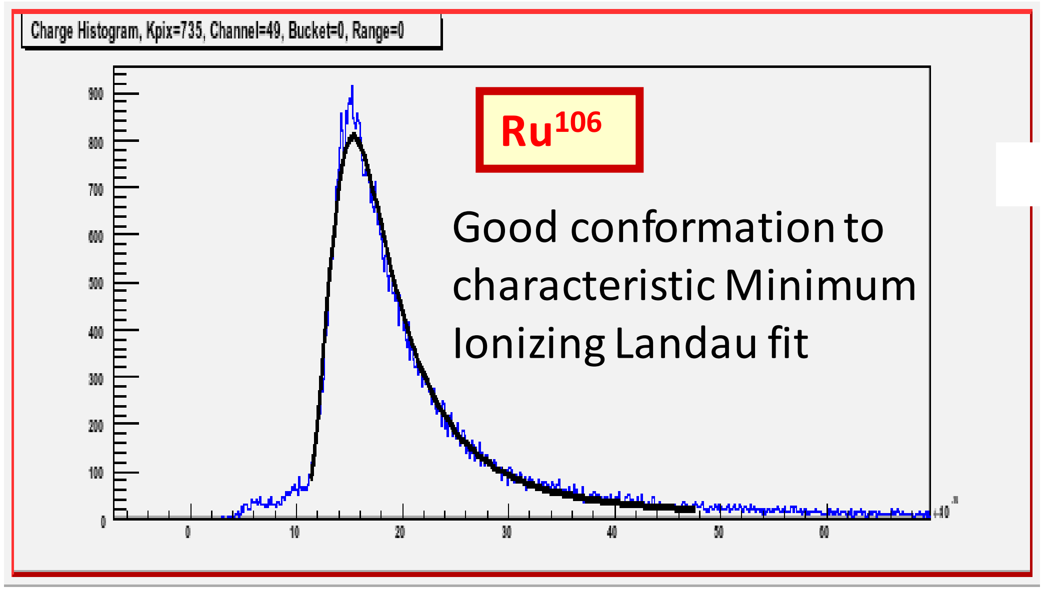




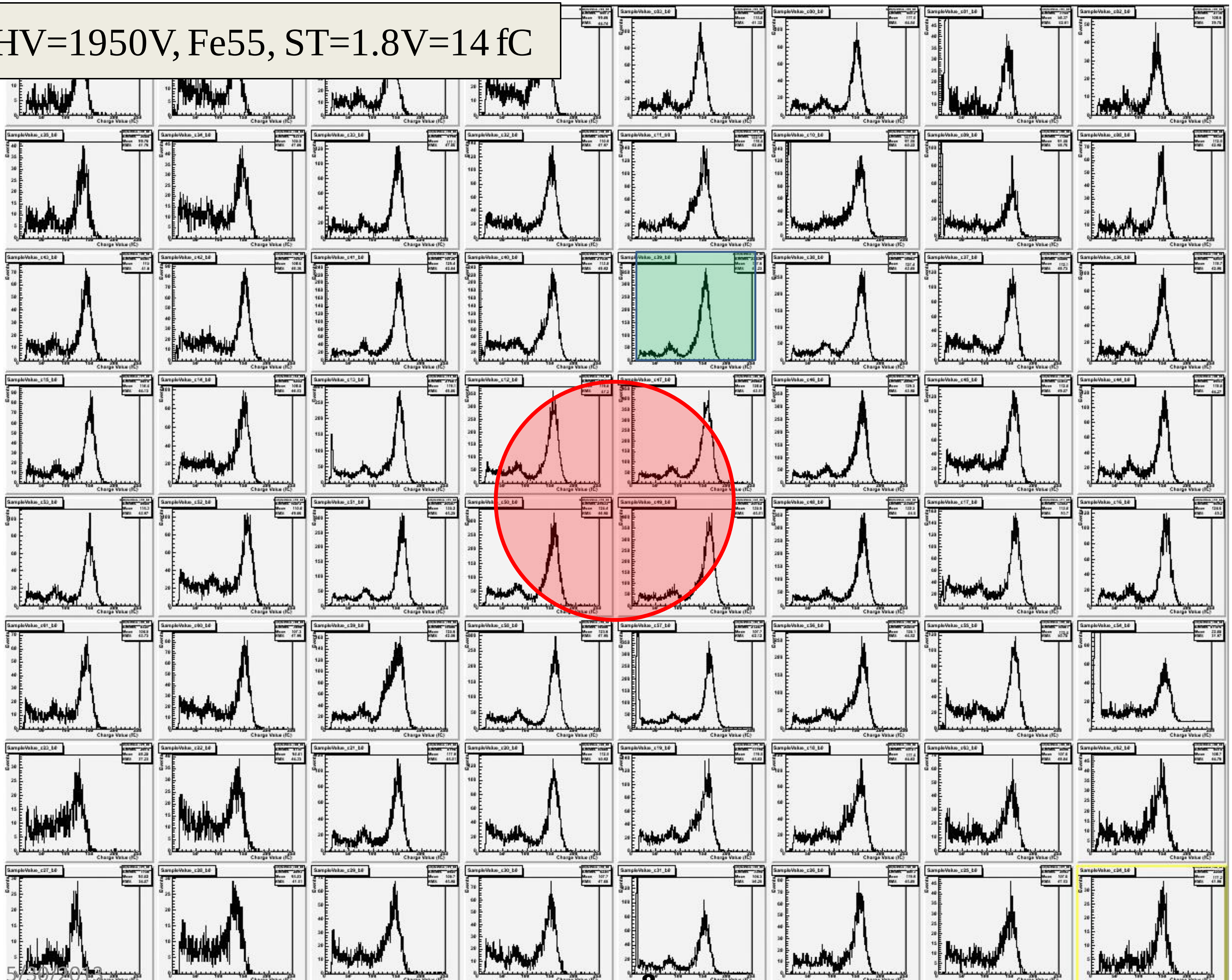
*Many thanks to ANL colleagues! J. Repond, L. Xia, G. Drake, J. Schleroth, J. Smith (UTA student at ANL) and H. Weerts.

GEM+KPiX7 Fe^{55} and Ru^{106} Spectra

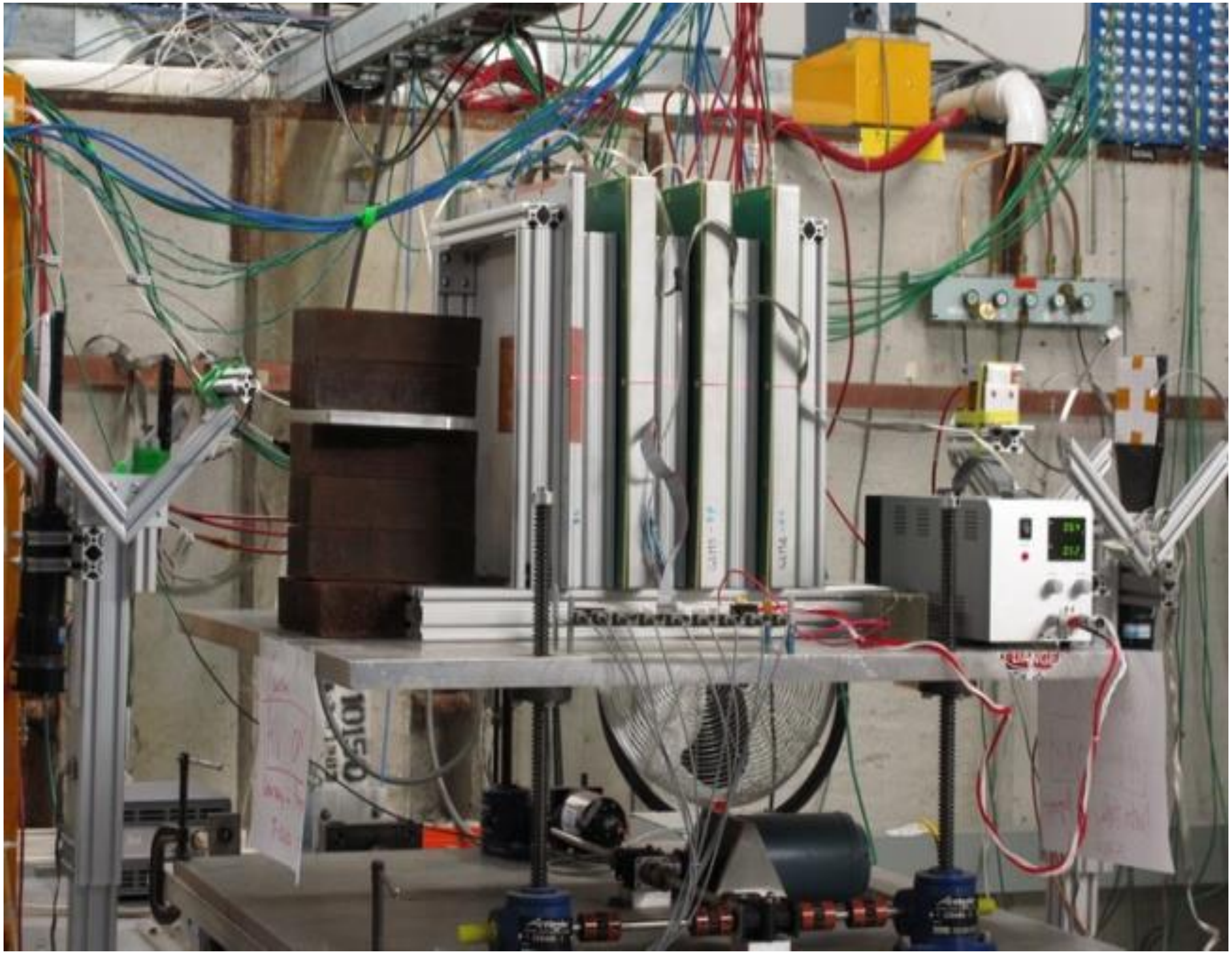




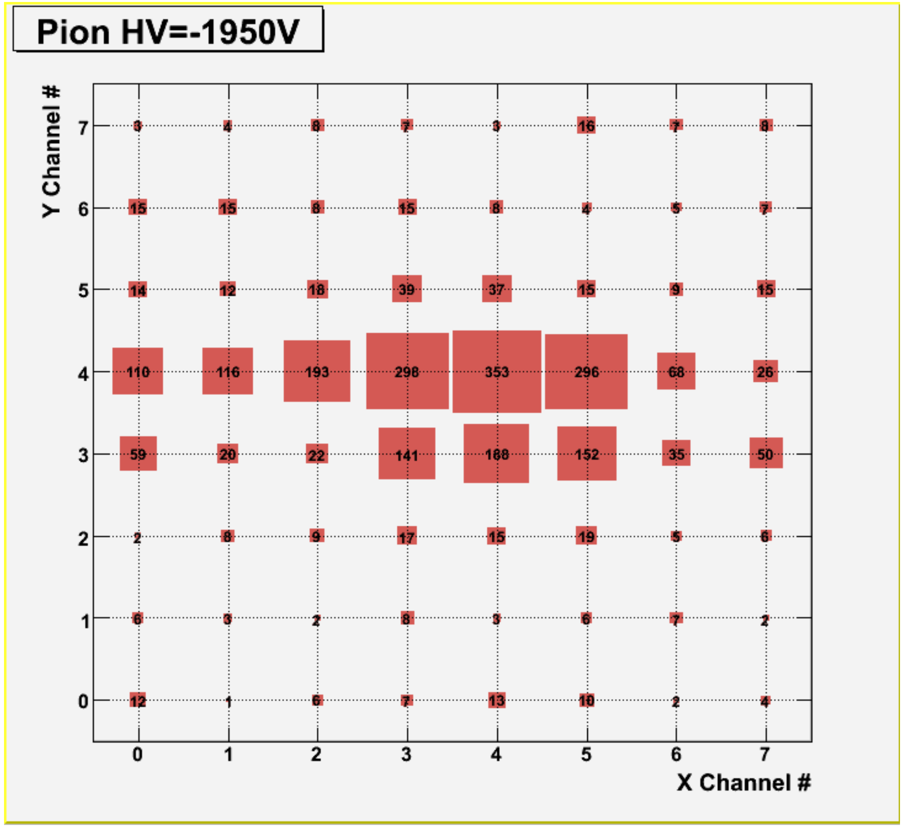
HV=1950V, Fe55, ST=1.8V=14 fC

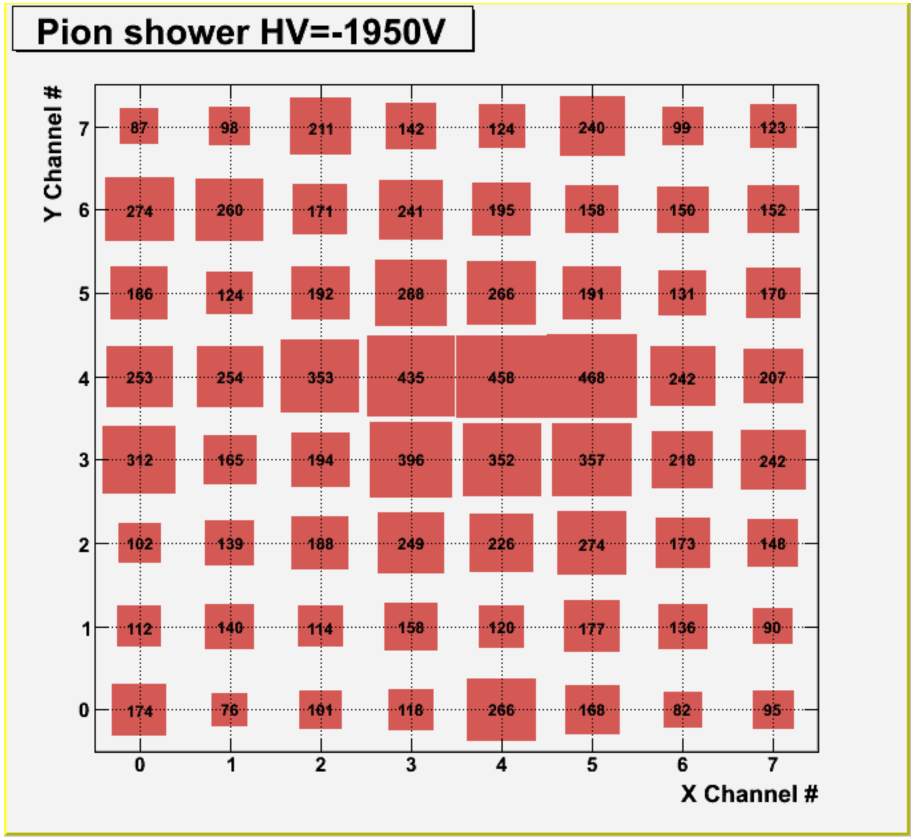


T-1010 Experiment Setup



Hit Map for Pions vs Pion Showers (KPiX)

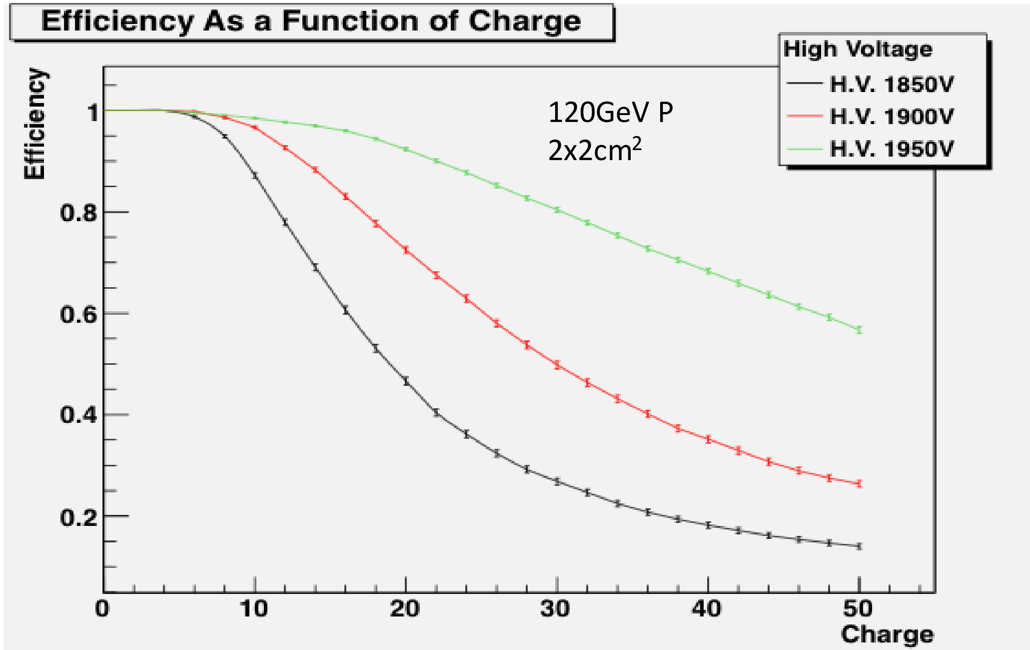


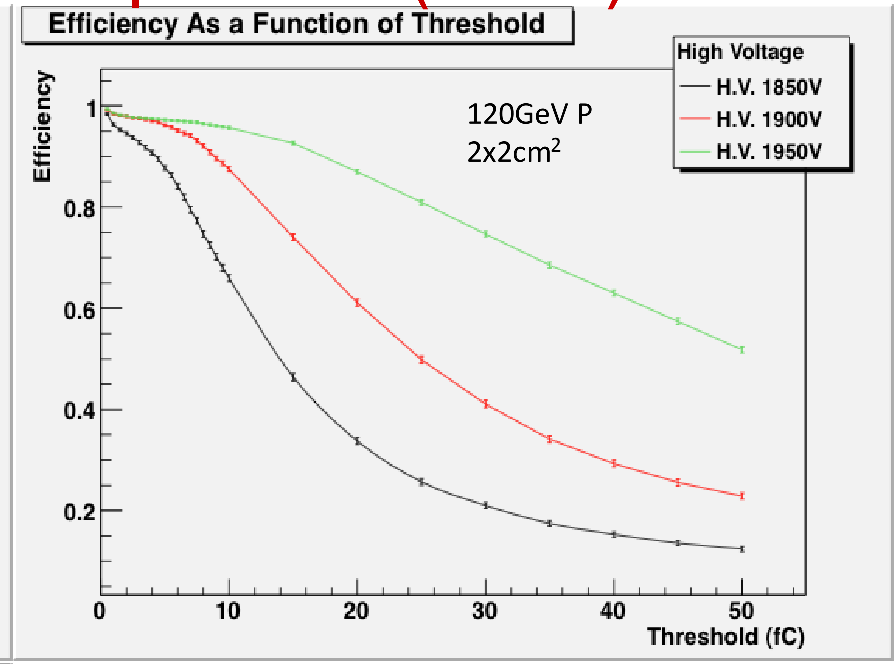


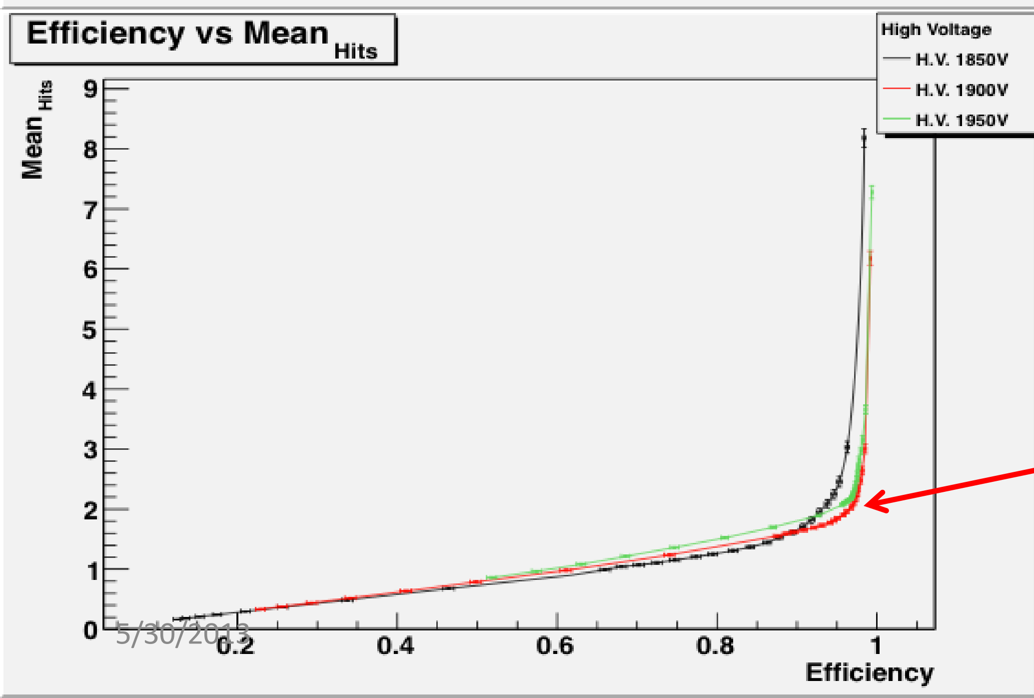
Hits above 5fC were counted and normalized to 1000

Demonstrates the KPIX capability to take many hits simultaneously

Efficiencies and Hit multiplicities (KPiX)







Preliminary results, pressure corrected

Potential operating region:
- High efficiency
- Low multiplicity

KPiX Long-term stability

- Determine the degree of MPV variation over extended period

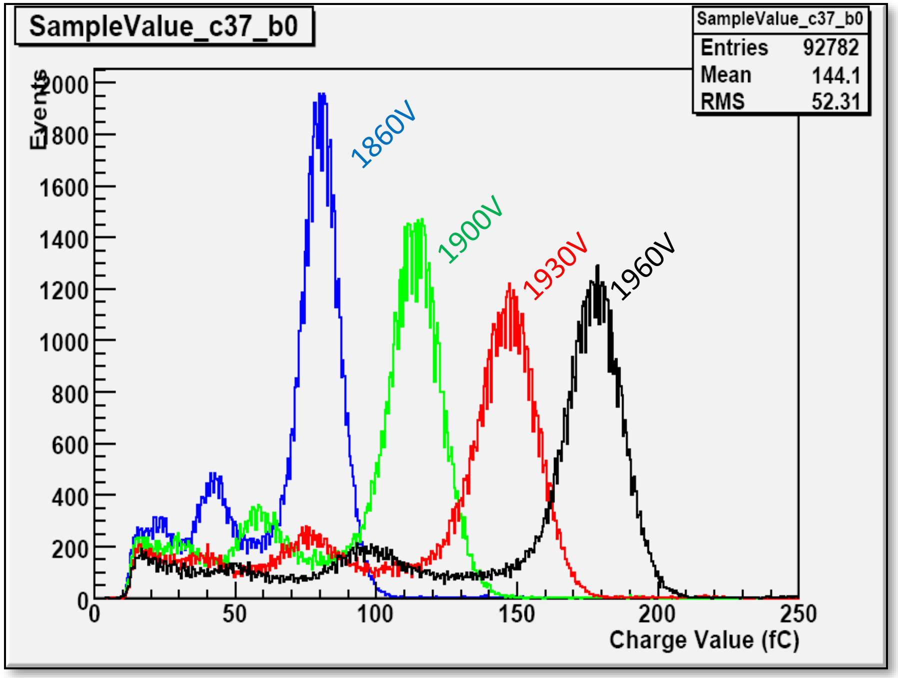
- Monitor atmospheric pressure for corrections

- Data taken on continuous basis by UTA students

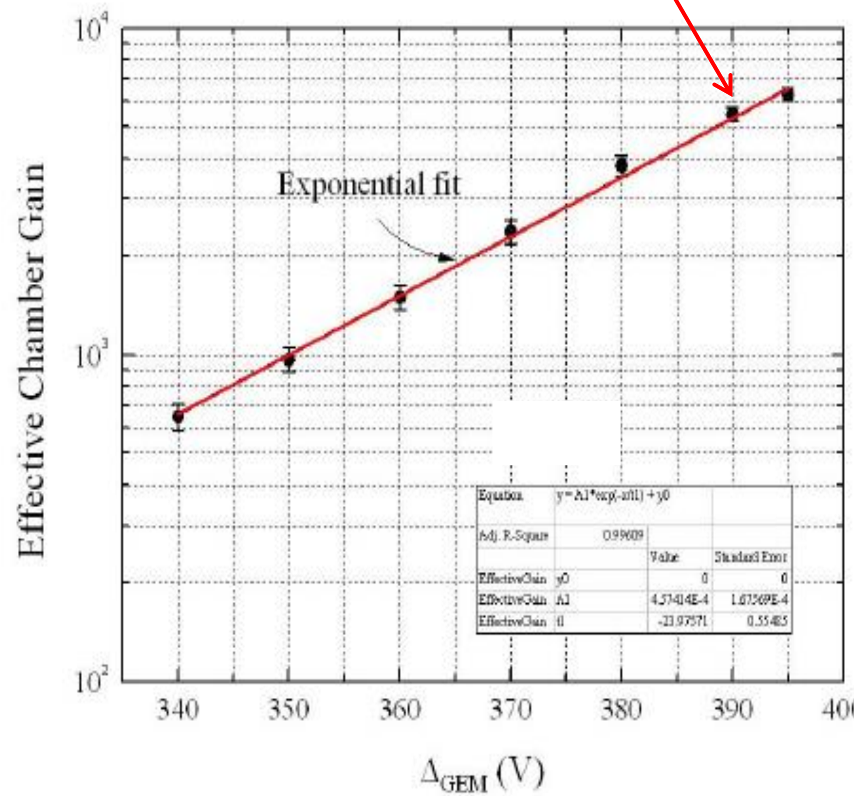
- Determine stability vs. probable threshold(s) for digital hadron calorimeter operation.

- Assess whether HV operating region is sufficiently above threshold *and* away from any discharge region.

Gain vs HV

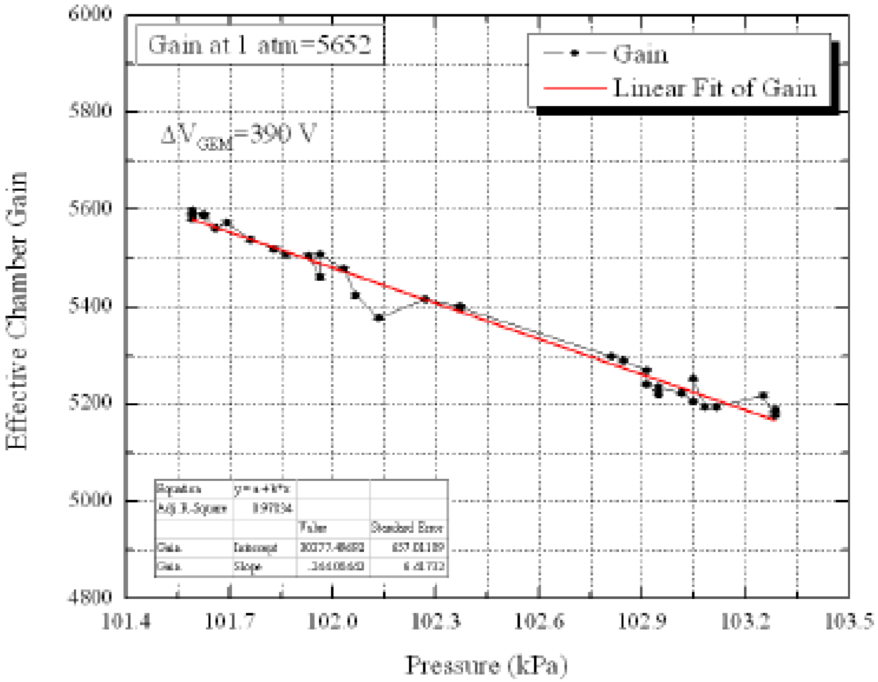


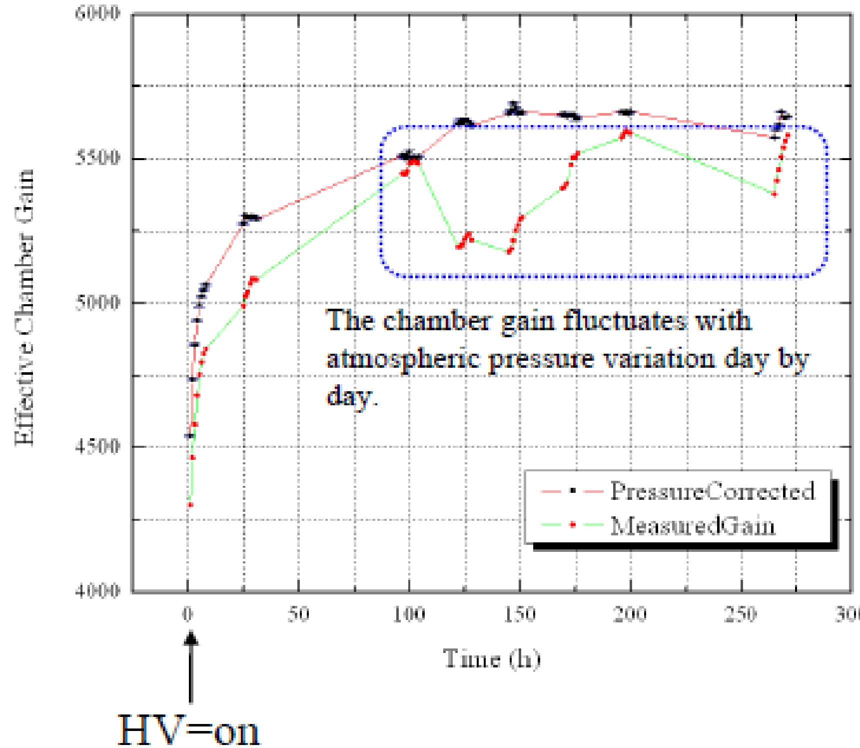
Typical operating region:
Gain ~5-6000



Pressure Dependence of Gain

HV =1950V (ΔV_{GEM}=390 V)





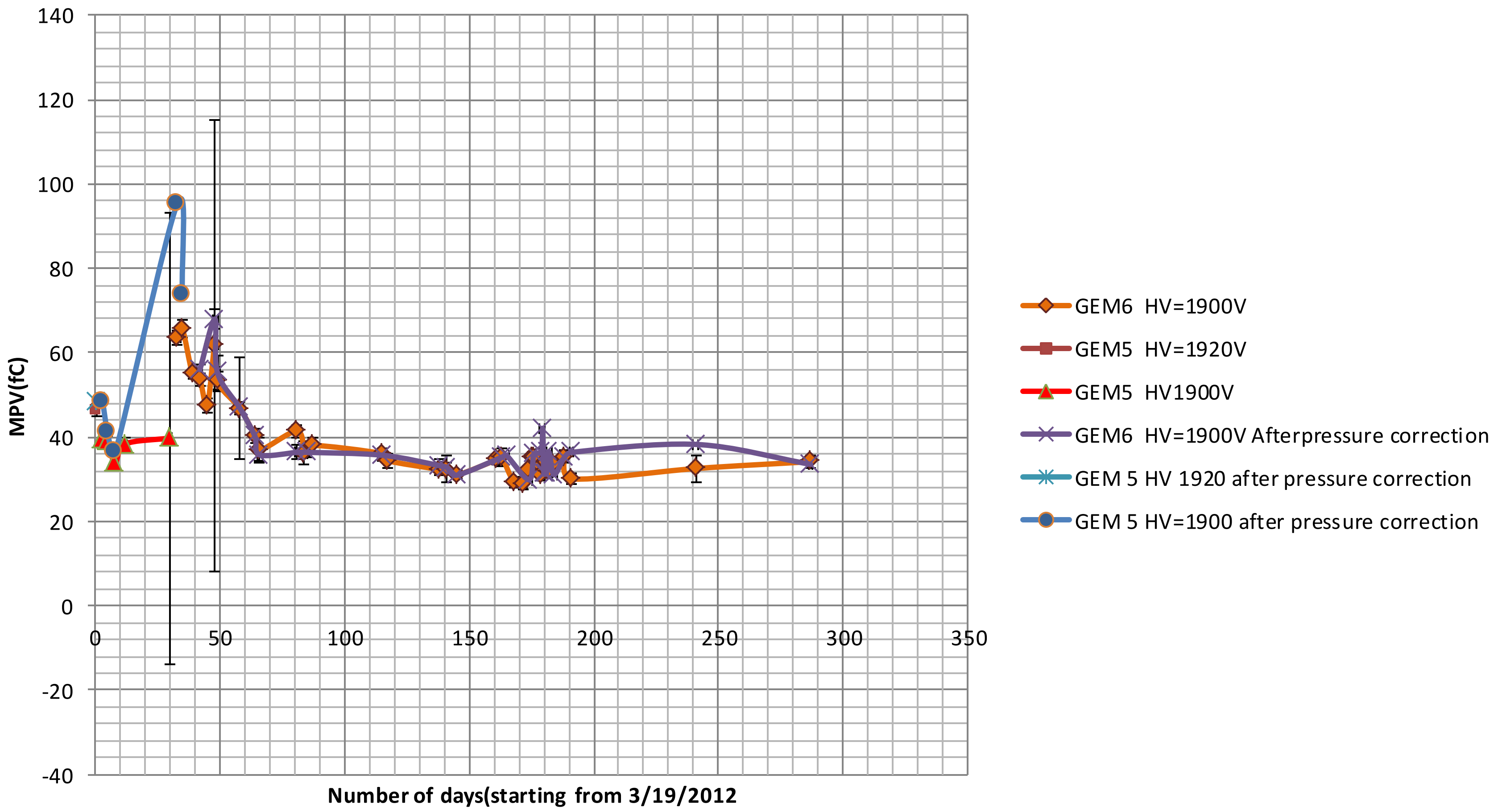
We use an open gas system (gas flows at atmospheric pressure).

Thus, pressure inside chamber is affected by the atmospheric pressure directly.

This pressure change affects the chamber gain.

The chamber gains were recalculated to the values at 1 atm.

GEM/DHCAL - KPiX Long-term stability



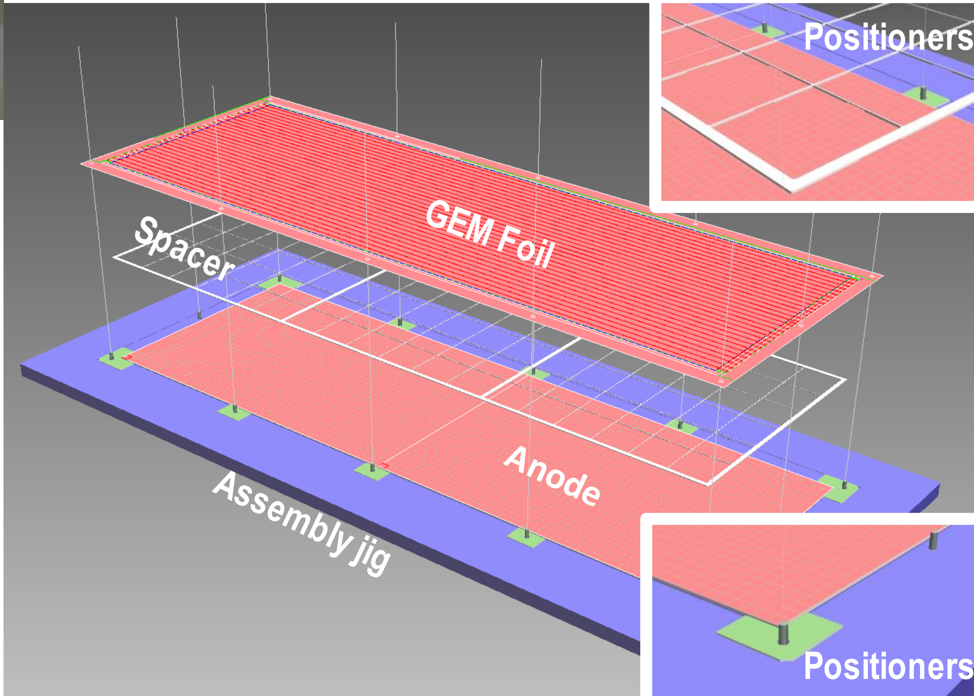
KPiX intrinsic noise level ~ 0.5 fC

Large (100cm x 33cm) GEM Planes

Class 10,000 clean room (12’x8’) construction completed

Two 33cmx100cm chamber parts delivered

Jig for 33cmx100cm chamber procured

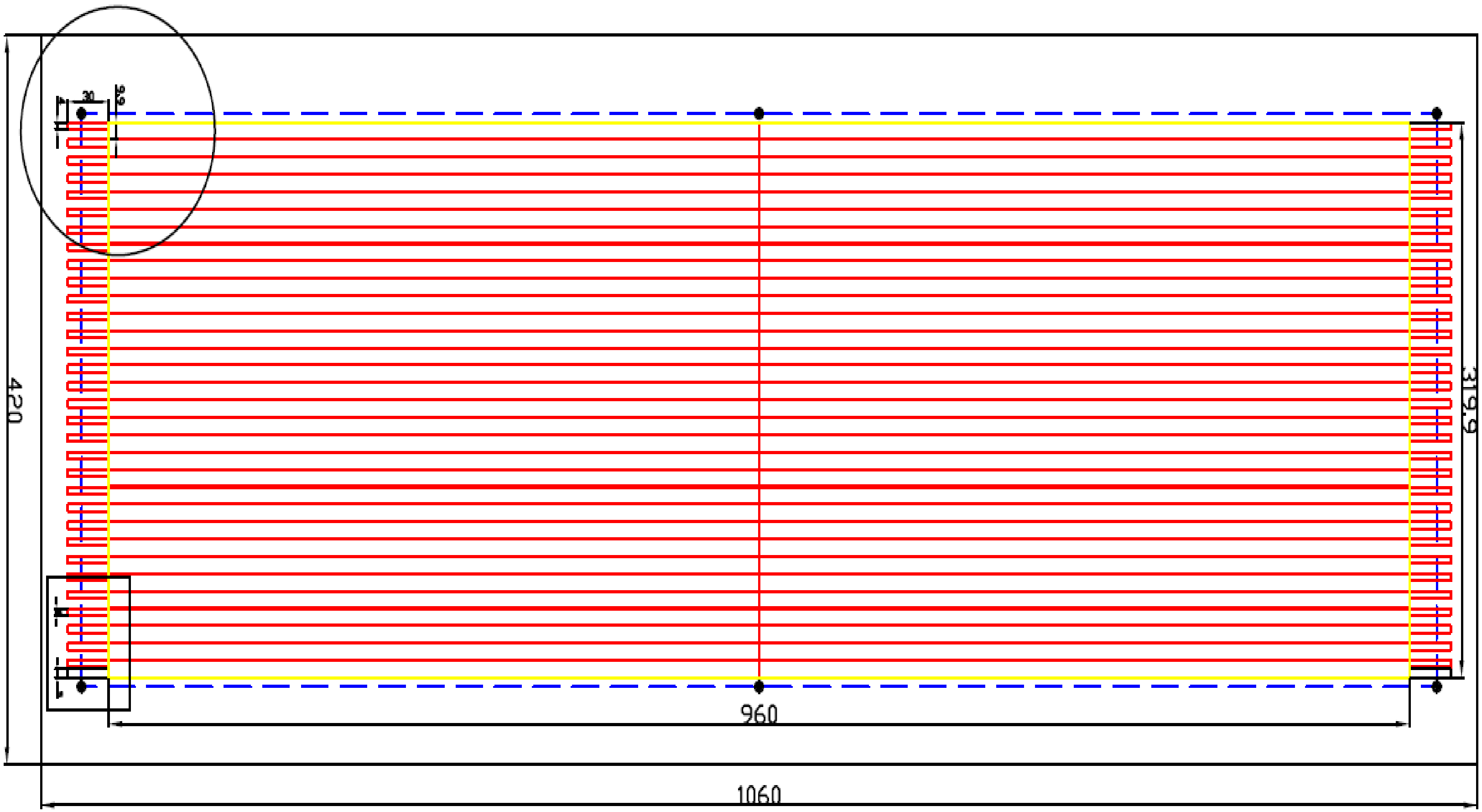


33cmx100cm GEM Foil Design

Active area 960x306 mm^2

Number of HV sectors = 31 to minimize loss in case of damage

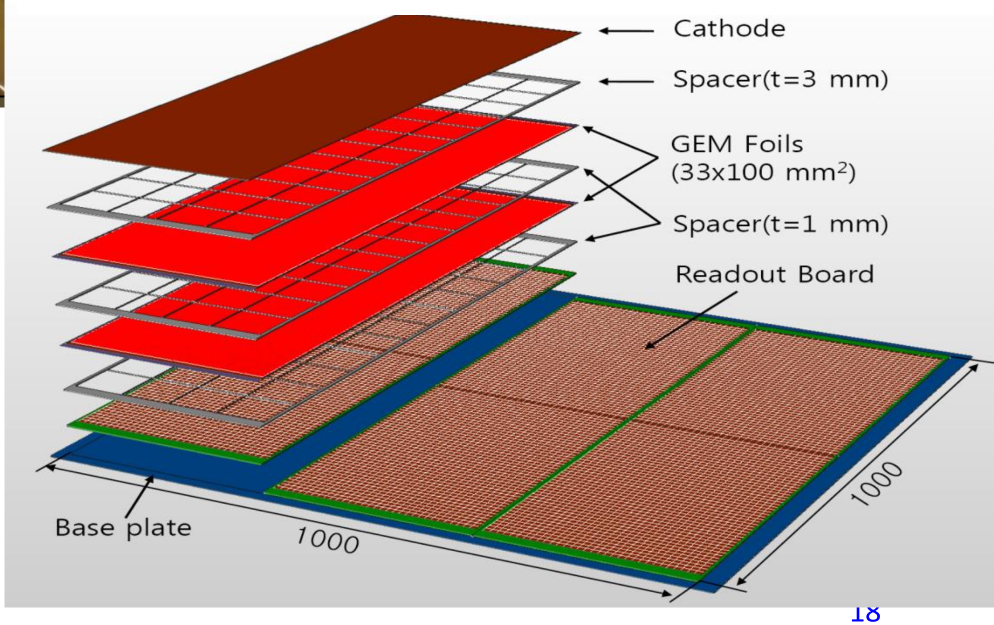
HV sector dimension= 9.9x950 mm^2



Toward 100cmx100cm GEM Planes

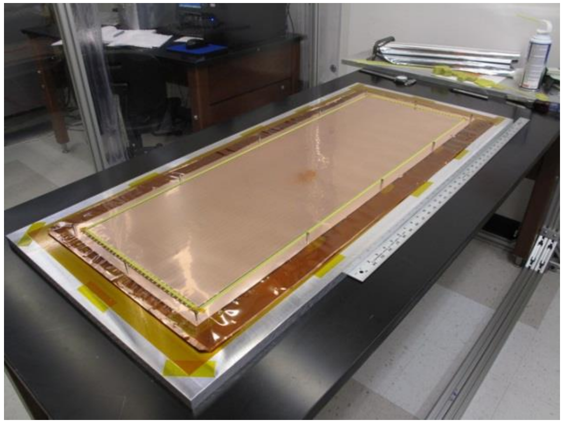
CERN GDD Workshop delivered the first 5 of 33cmx100cm GEM foils ➔ Qualification completed!!

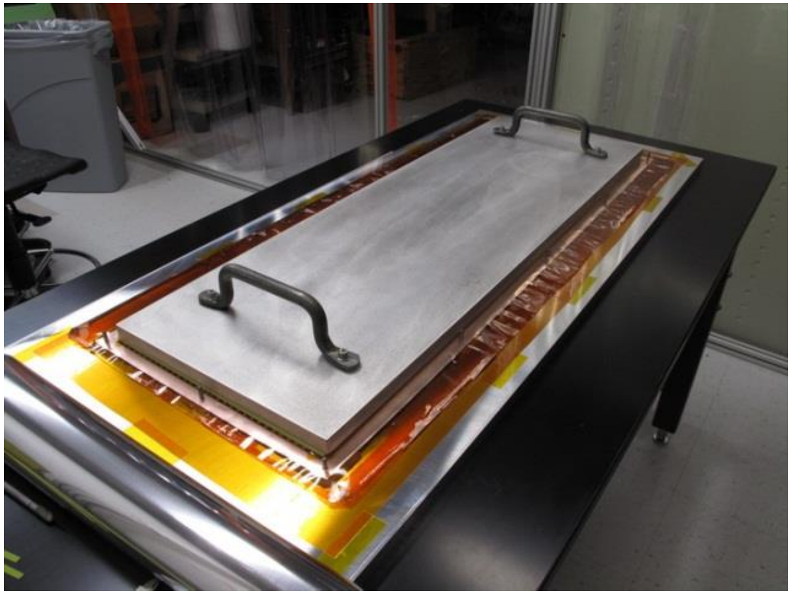
Foil Name	$N_{strip-pass}$	$<t_{saturation}>$	$N_{strip}>2000s$	Qualification	Note
LGEM 1	31	1725 s	4	Pass-med	Strips 1, 2, 10 & 23 >2000s
LGEM 2	30	1692 s	3	Pass-med	Strip 22 failed Strips 4, 5 & 29>2000s
LGEM 3	31	1484 s	0	Pass-high	
LGEM 4	31	1491 s	1	Pass-high	Strip 20 >2000 s
LGEM 5	Untested				Free-Delivered broken

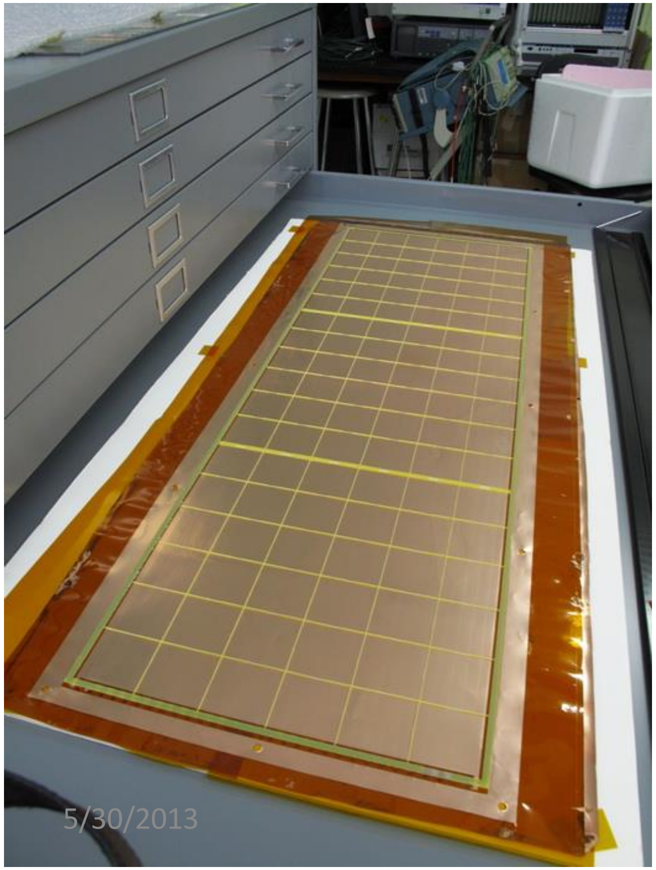


Each of the GEM 100cmx100cm planes will consist of three 33cmx100cm unit chambers

Preparation for LGEM Assembly







Status:

- Working with SLAC to design/produce anode boards

- On hold due to difficulties with detector R&D funding

- Now have secured FY13 support – complete/test one large chamber

THGEM for DHCAL

- **S. Bressler, L. Arazi, L. Moleri, A. Rubin, M. Pitt, A. Breskin**
Weizmann Institute
- **C. D. A. Azevedo, J. F. C. A. Veloso**
- *Aveiro Univ*
- **H. Natal da Luz, J. M. F. dos Santos**
- *Coimbra Univ*
- **E. Oliveri**
- *CERN*

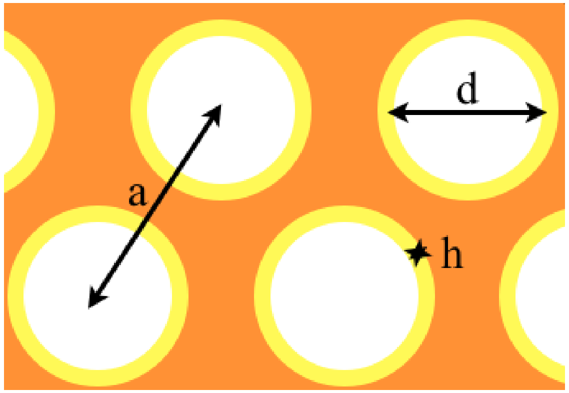
A. White
- *UTA*

arXiv:1305.4657
S. Bressler et al.
Beam studies of novel THGEM-based potential sampling elements for Digital Hadron Calorimetry .
submitted to JINST

arXiv:1305.1585
L. Arazi et al.
Beam Studies of the Segmented Resistive WELL: a Potential Thin Sampling Element for DHCAL
Vienna Conference on Instrumentation, February 2013

THGEM structures - Standard & WELL THGEM

- THick GEM (THGEM) is a 10 fold expanded GEM
- Typical parameters: a ~ 1 mm, d ~ 0.5 mm, h ~ 0.1 mm

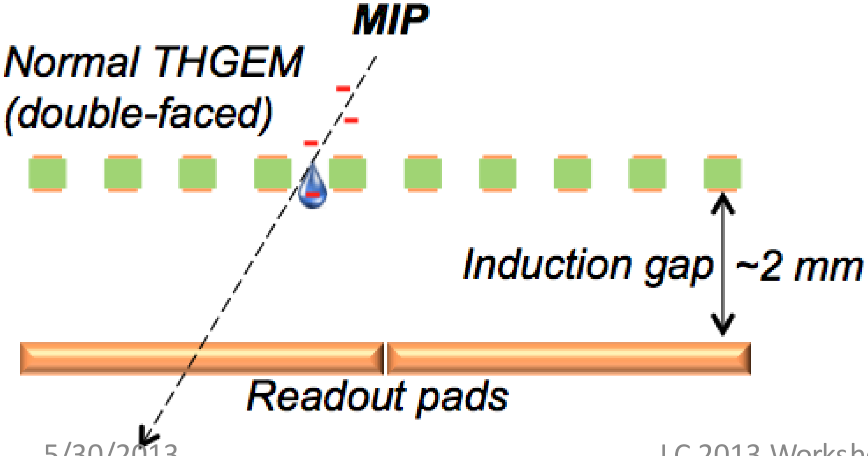


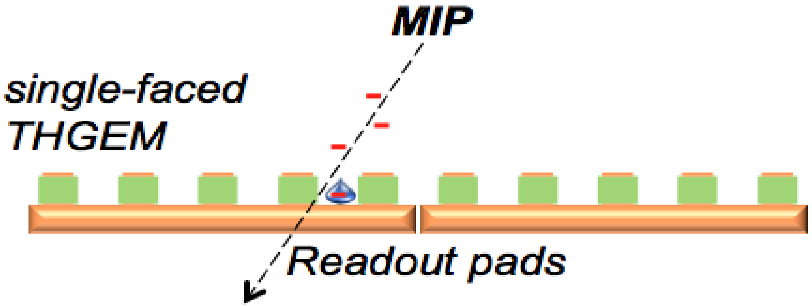
Standard THGEM

- Cu coated on both sides
- Operated with induction gap

WELL THGEM

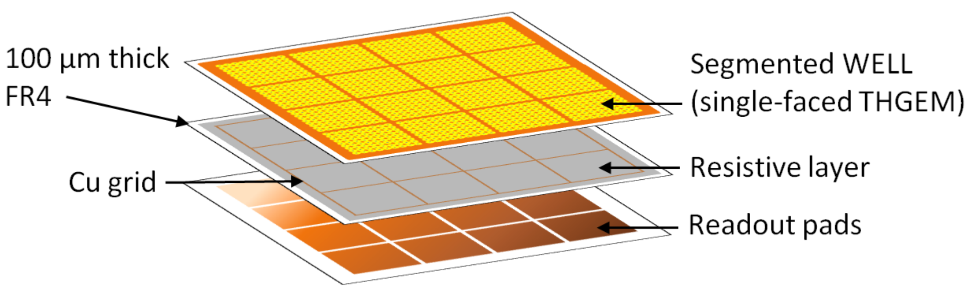
- Cu coated on one side
- No induction gap - electrode attached to the anode

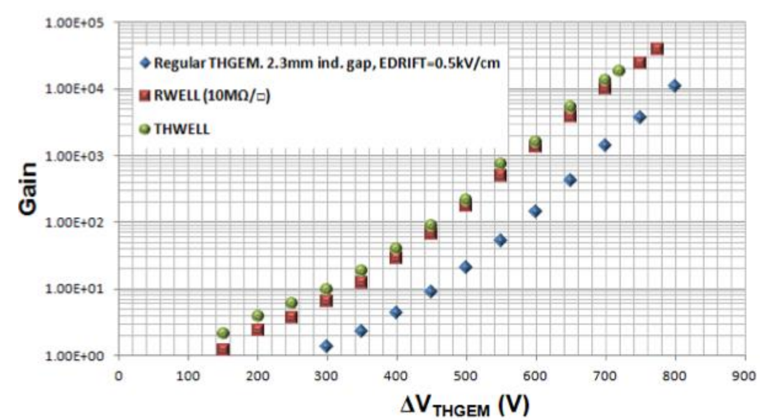




NEW THGEM structure - SRWELL

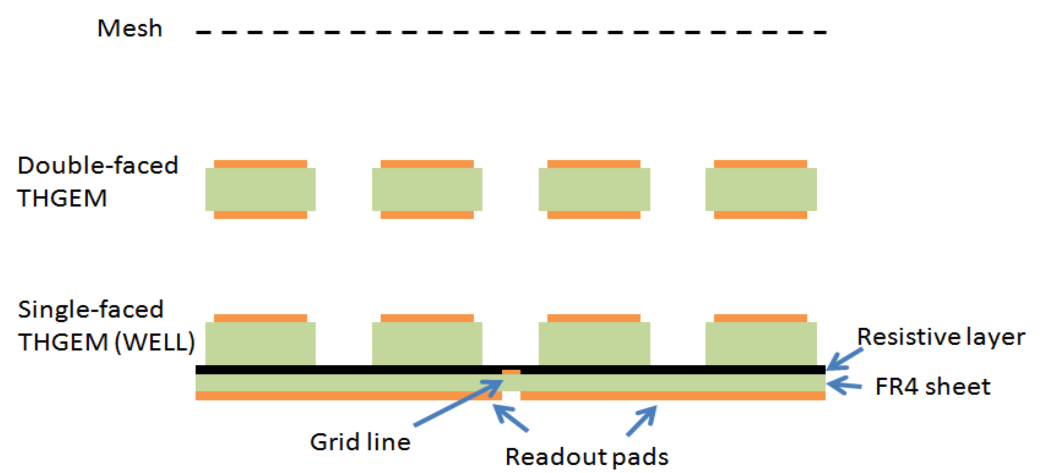
- *Segmented Resistive WELL*:
  - **WELL** THGEM coupled to a **resistive** layer (RL)
  - The charge is induced on the readout pads
  - The pads are separated from the RL by a thin insulating sheet
  - The RL quenches the energy of the occasional discharge
  - Cross talk due to charge propagation along the resistive layer is avoided by adding a Cu grid to the resistive layer
  - The electrode is **segmented** accordingly to prevent discharges in holes residing directly above grid lines





Double-stage: THGEM+ SRWELL

- **Multi-stage configurations** are commonly used
  - More stable
  - Higher maximal achievable gain

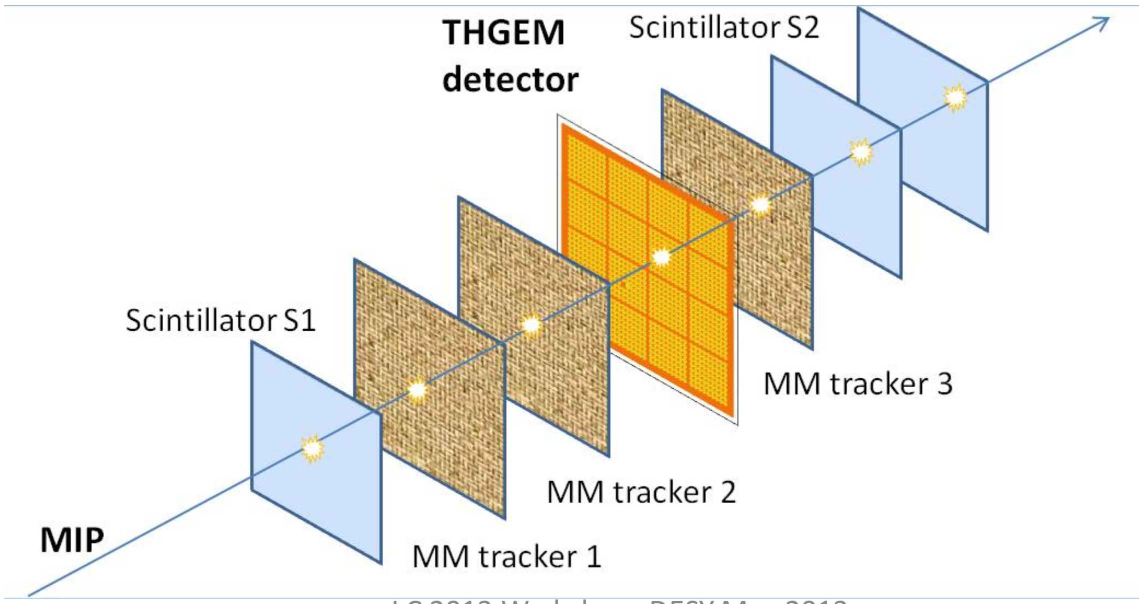


But

  - thicker configuration
  - More expensive
- **SRWELL-based double-stage configurations**
  - Stable
  - Thin; **$\leq$ 6 mm** including drift gap
  - Studied systematically in the lab

Beam test evaluation - The setup

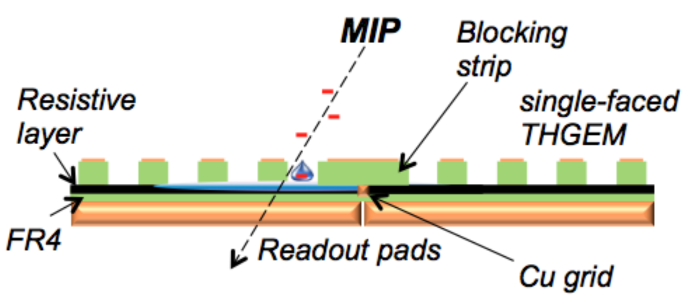
- 100x100 mm^2 THGEM detectors placed along the beam; 80x80 mm^2 coverage
- RD51 telescope
  - Three scintillators for triggering; 100x100 mm^2 coverage
  - Three MM for accurate tracking; 60x60 mm^2 coverage
- Single SRS front and card for the tracker and the detector
- All the measurements are wrt the MM track trajectory

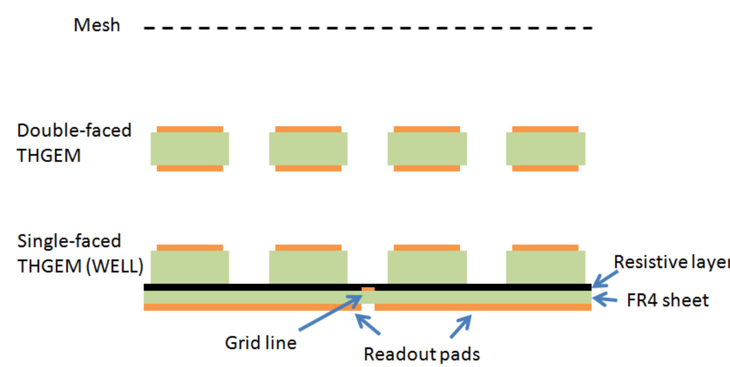


Beam test evaluation - The configurations

- Five configurations were tested
  - Not all of them to the same level of detail

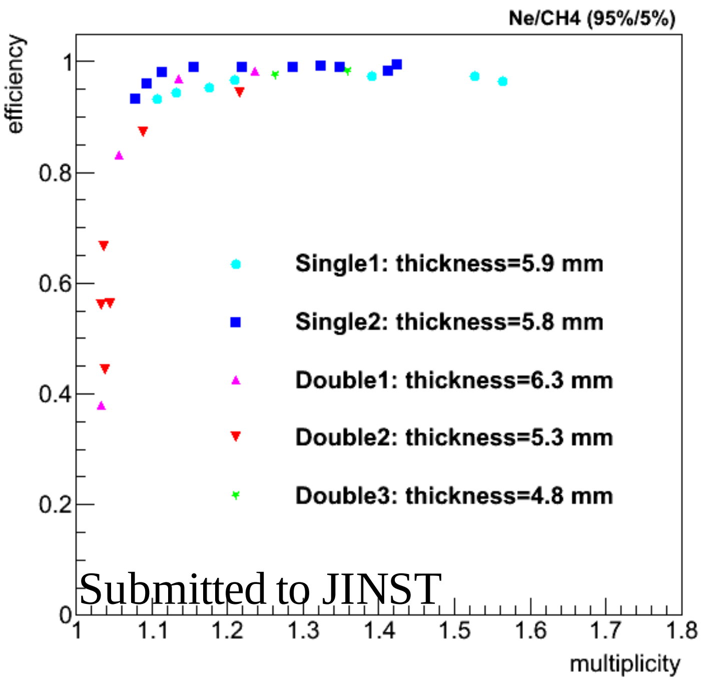
Conf.	Thickness [mm]	Transfer [mm]	Drift [mm]	Total [mm]	Resistivity
Single1	0.4	-	5.5	5.9	10 MΩ/□
Single2	0.8	-	5	5.8	10 MΩ/□
Double1	0.4/0.4	1.5	4	6.3	20 MΩ/□
Double2	0.4/0.4	1.5	3	5.3	20 MΩ/□
Double3	0.4/0.4	1.5	2.5	4.8	10 MΩ/□





Beam test evaluation - Performance in muon beam

- High efficiency and low pad multiplicity were recorded with all the configurations

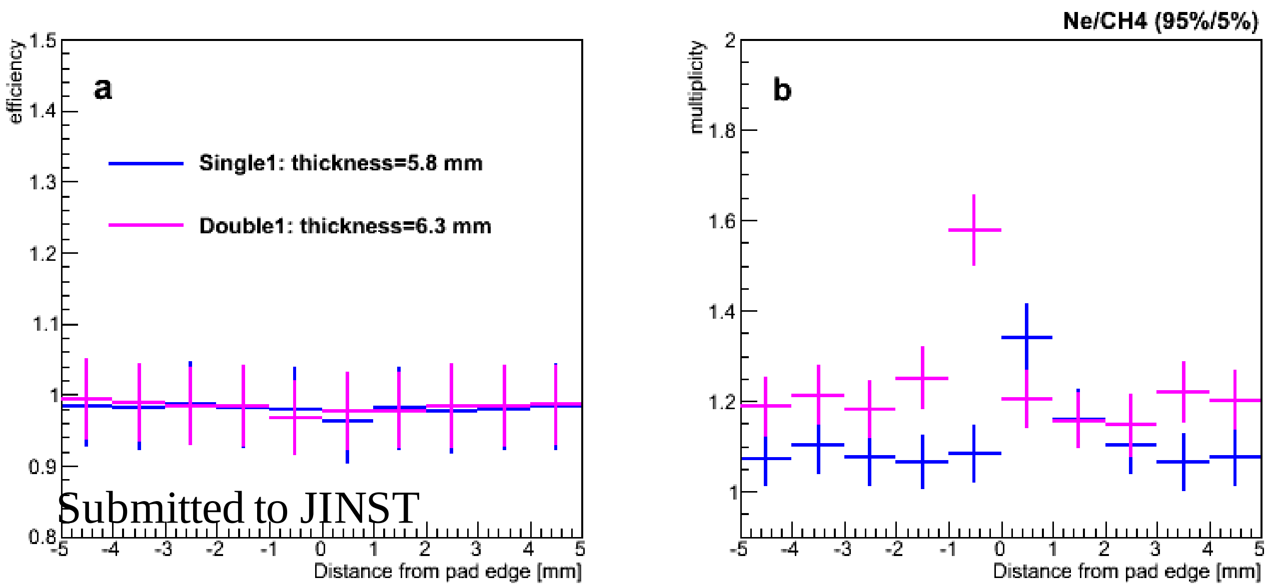


Conf.	efficiency	multiplicity	Eff. gain
Single1	0.97	1.2	1200
Single2	0.98 / 0.99	1.1 / 1.2	2000
Double1	0.98	1.2	6500
Double2	0.95	1.2	8200
Double3	0.98	1.3	4000

- Plenty of room for optimization
- HV configuration
- Gaps

Beam test evaluation - Performance in muon beam

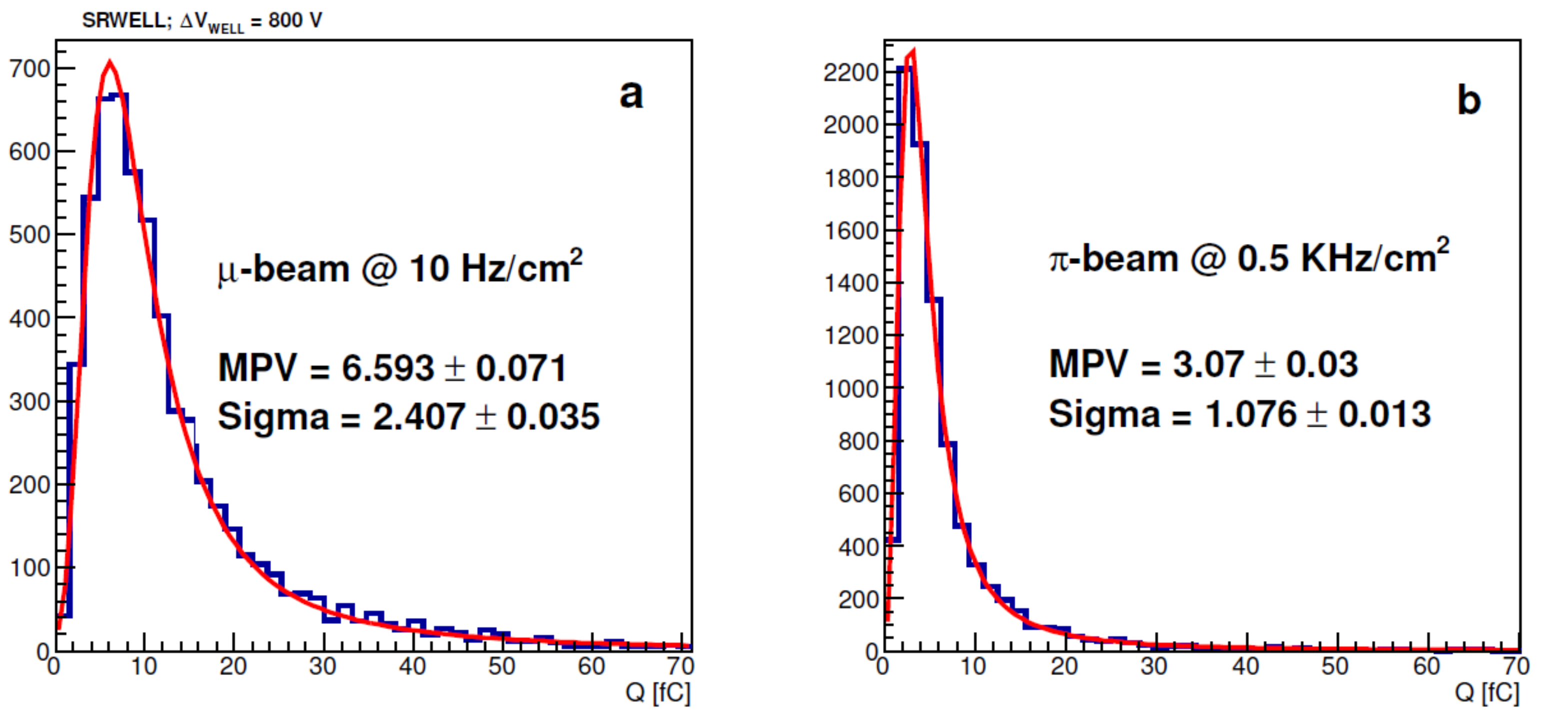
- Take advantage of the accurate tracking system
- Measure efficiency and multiplicity as a function of the distance from the edge of the pads
- As expected - small efficiency drop and higher multiplicity close to the edge of the pads



- The pad-multiplicity provides additional information concerning the track position, which could be exploited

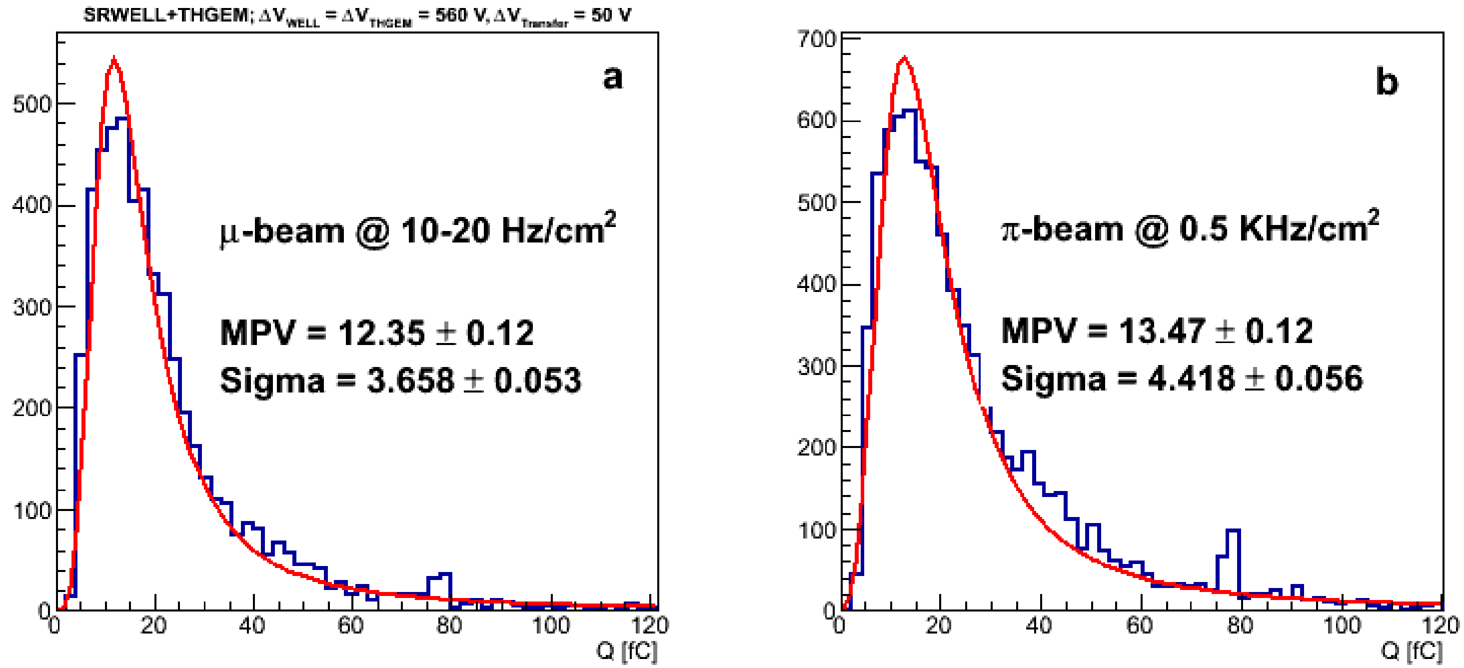
Beam test evaluation - Performance in pion beam

- Single-stage detector:
  - Significant gain drop was recorded in the transition from low rate muon beam to high rate pion beam
  - Under study



Beam test evaluation - Performance in pion beam

- Double-stage detector:
  - Stable and similar operation was recorded both in muon and pion beam
  - No gain drops where recorded
    - With respect to SRWELL - each element has lower HV for the same gain



Beam test evaluation - Discharge analysis

- Two types:
  - Large: voltage drop in the range 50-150 V
  - Micro: voltage drop of order 5 V
- Large discharges:
  - probability $<10^{-6}$ in rates up to several kHz/cm^2 with all the configurations
- Double stage:
  - No large discharges
  - *Micro discharges*
    - Probability: 10^{-7} muons, 10^{-6} pions
    - Mostly correlated with the beam spills
    - Not all the electrodes are involved
    - No effect on the gain and the efficiency

THGEM - Summary

- Beam studies of thin single-SRWELL and double-stage THGEM-SRWELL were done with 100x100mm^2 detectors
- Total thickness of 5-6 mm (excluding readout electronics), with 1 x 1 cm^2 pads inductively coupled through a resistive layer to APV-SRS readout electronics, were investigated with muons and pions.
- Detection efficiencies in the 98% range were recorded with an average pad-multiplicity of ~1.1.
- Efficient discharge damping, with few-volt potential drops; discharge probabilities were ~10^{-7} for muons and 10^{-6} for pions in the double-stage configuration, at rates of a few kHz/cm^2. Under study in single SRWELL
- These results + THGEM robustness against spark damage and their suitability for economic production over large areas make THGEM-based detectors highly competitive for DHCAL
- Status: Lab studies; 300x300 mm^2 in production; 1m^2 in design

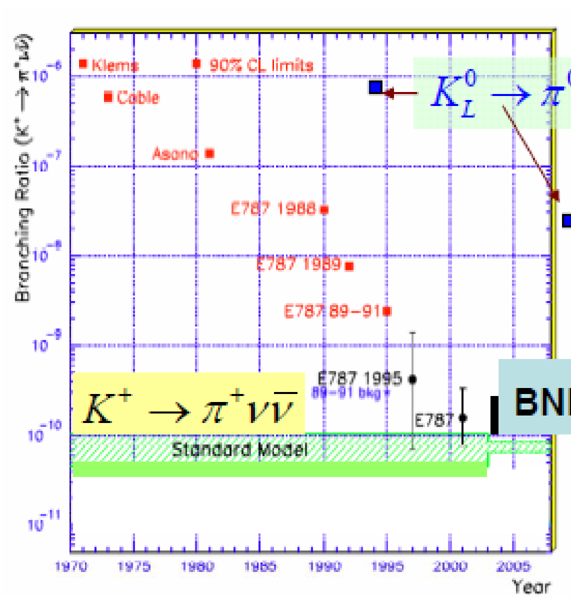
GEMs for Tracking

Range Stack for Rare Kaon Decay Experiment

Precise Measurement of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

$B_{SM}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (7.8 \pm 0.8) \times 10^{-11}$

$B_{SM}(K_L^0 \rightarrow \pi^0 \nu \bar{\nu}) = (2.8 \pm 0.4) \times 10^{-11}$

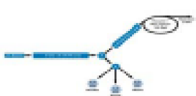


$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$

*JPARC KOTO (Phase 1, $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ to SM observation level) *

BNL :7 events $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

100 ***CERN NA62***

Project X 

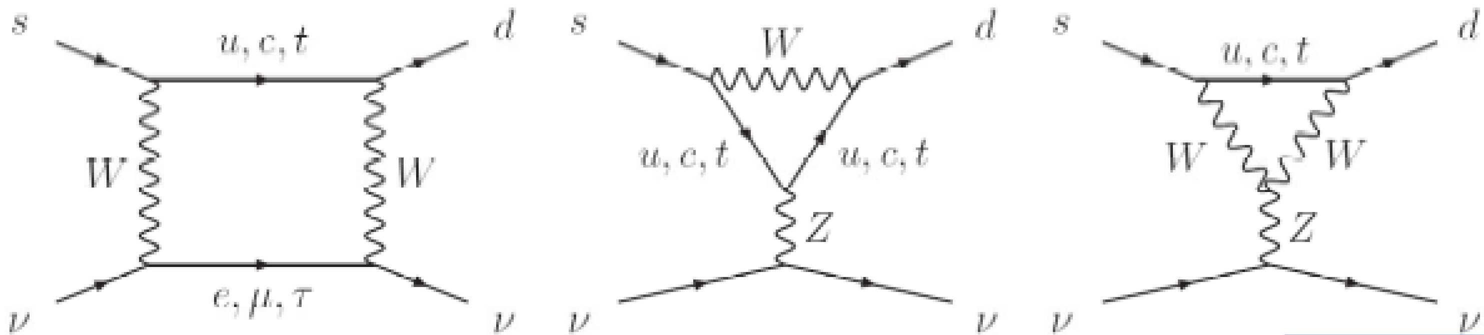
*** ORKA***

$K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$ 1000 $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

6

$K^+ \to \pi^+ \nu \bar{\nu}$ in the Standard Model

One of the few precisely precicted FCNC decays with quarks.



$$B_{SM}(K^+ \to \pi^+ \nu \bar{\nu}) = (7.8 \pm 0.8) \text{ x } 10^{-11}$$

ORKA aims for
1000 event
sensitivity:
30% deviation from
the SM would be a
5σ signal of NP

Range Stack in ORKA detector

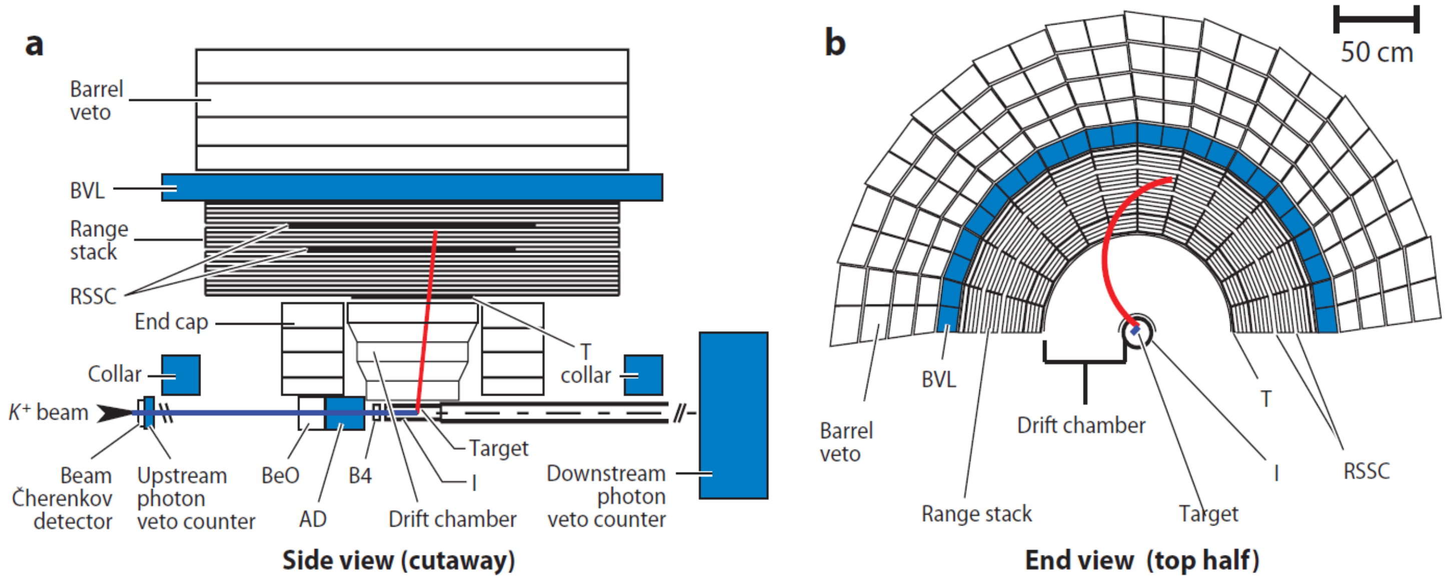
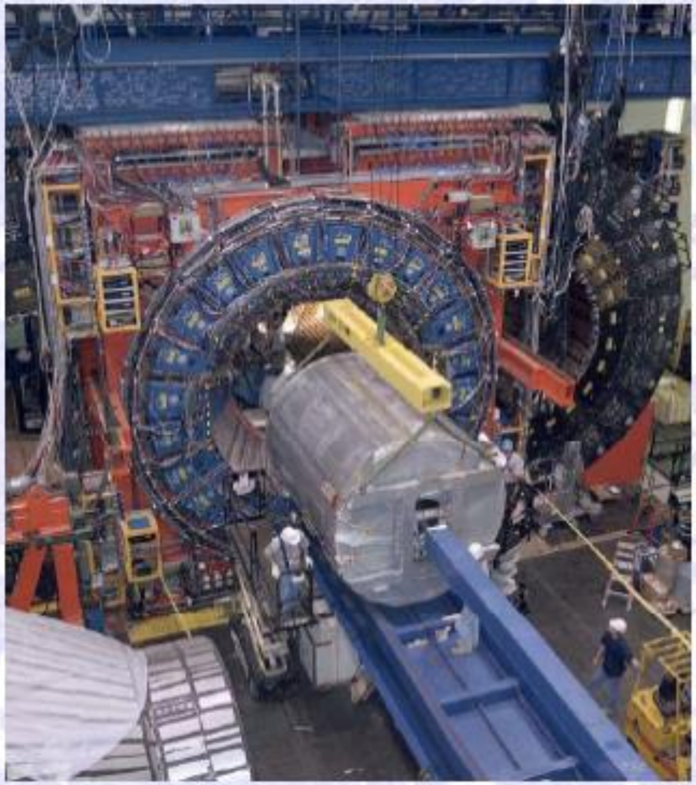


Figure 1

Elevation side view and end view schematic of the BNL E787 and E949 technique. (*a*) The 700-MeV/*c* K^+ beam enters from the left. (*b*) The stopped K^+ decays in the stopping target, and the subsequent decay π^+ track is momentum-analyzed by the tracker. The decay π^+ then stops in the range stack, where its range and energy are measured. The range stack STRAW chamber (RSSC) measures the position of the putative charged pion with the range stack. The barrel veto liner (BVL) is an upgrade of photon veto performance in E949 and E787. Abbreviations: AD, active degrader; DPV, UPV.

RS: Measure the energy, range and decay sequence of charged particles with good resolution



The ORKA new detector payload replaces the CDF tracker volume-ε.

Steve Kettell with the BNL-E949 Central tracker (similar diameter to ORKA)

GEM in Range Stack

- Need highly efficient identification of the decay sequence

$$\pi \rightarrow \mu \rightarrow e$$

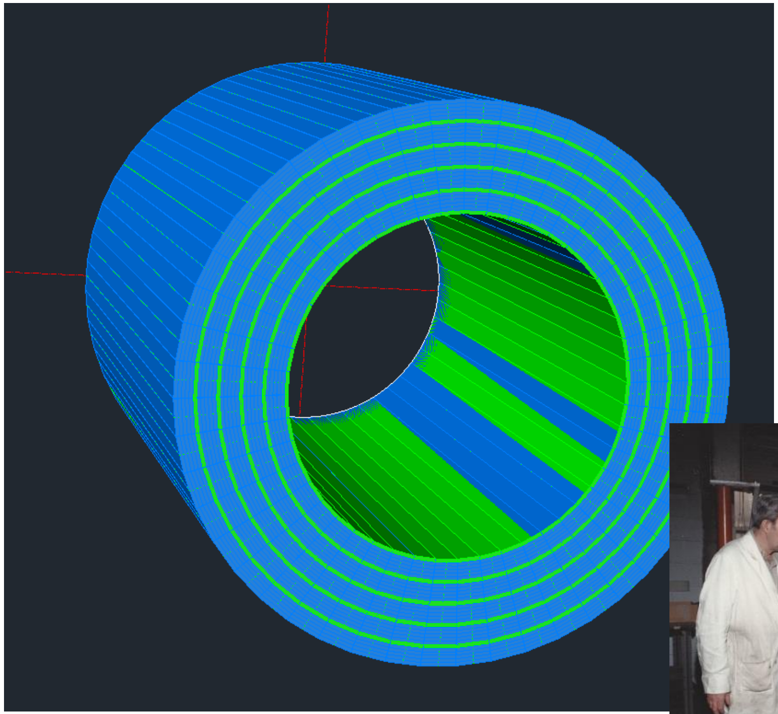
from pions ranging out in the stack.

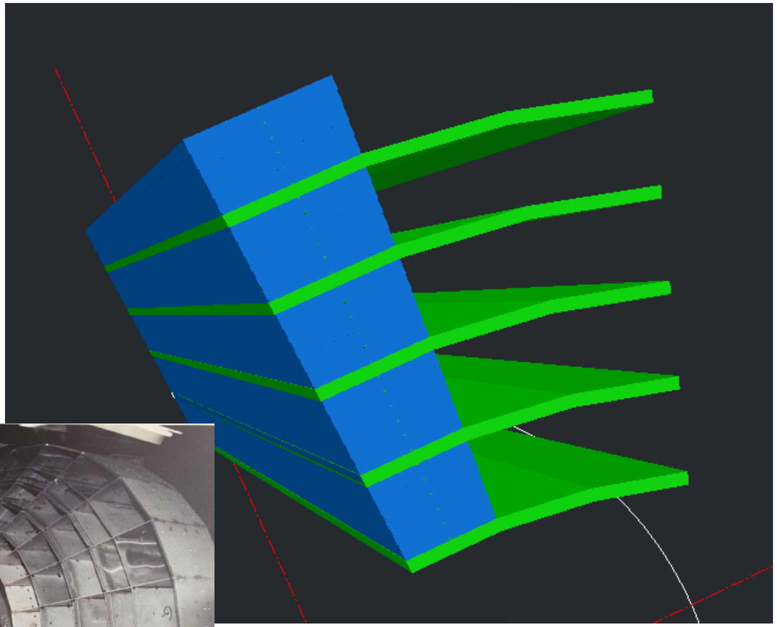
- The chambers must be low mass (in a previous experiment, straw tubes were used).

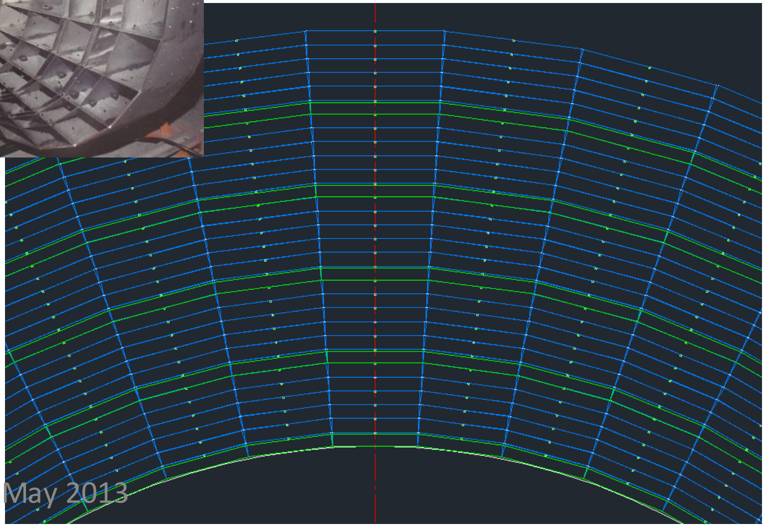
- High rate experiment :

Range stack total rate	3700 MHz
Range stack per channel	1300 KHz

GEM in Range Stack



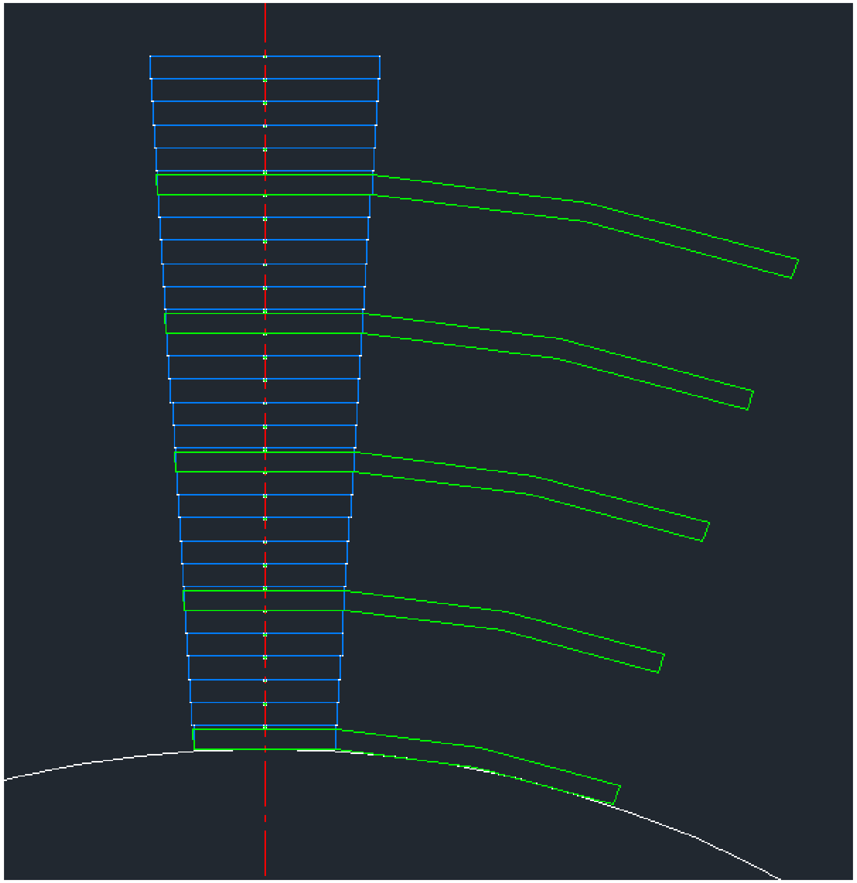


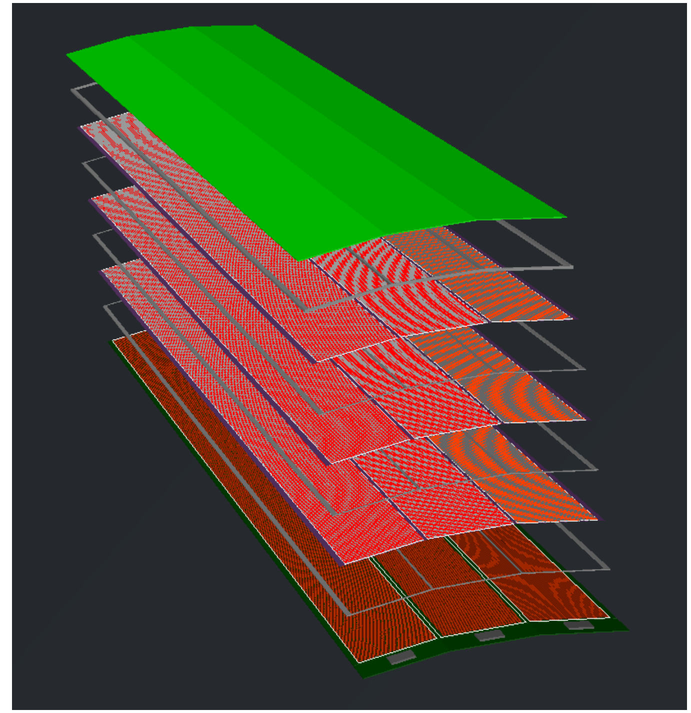


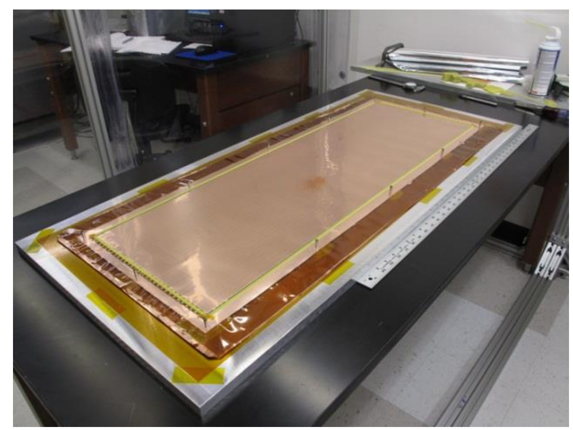
- Total 30 layers
- 48 scintillation sectors in 25 layers
- 16 sectors in 5 GEM layers(Green)
- Both ends are supported by spider-web like frame

GEM design with angled shape

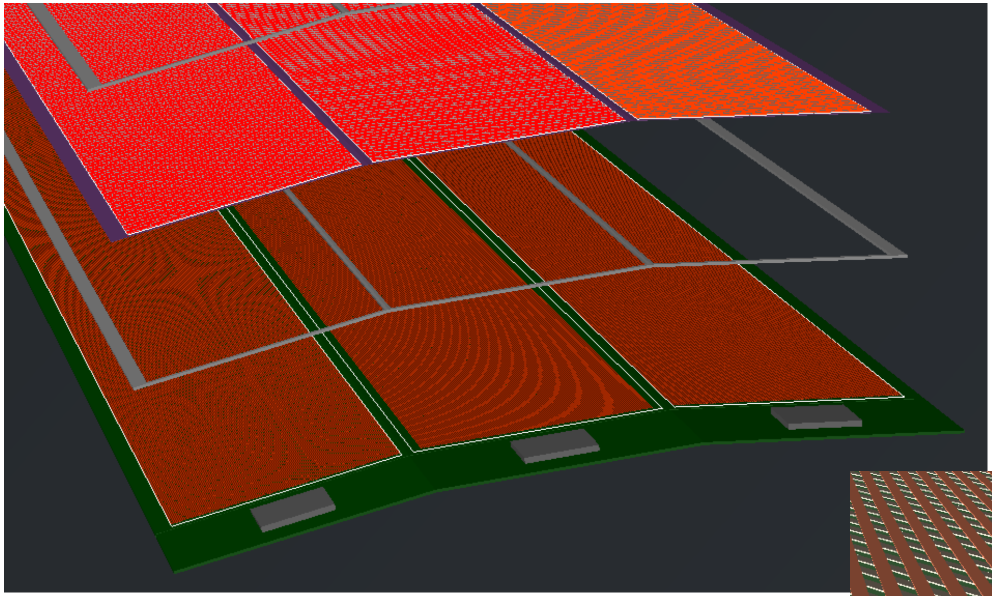
Triple GEMs with crossed strip readout structure



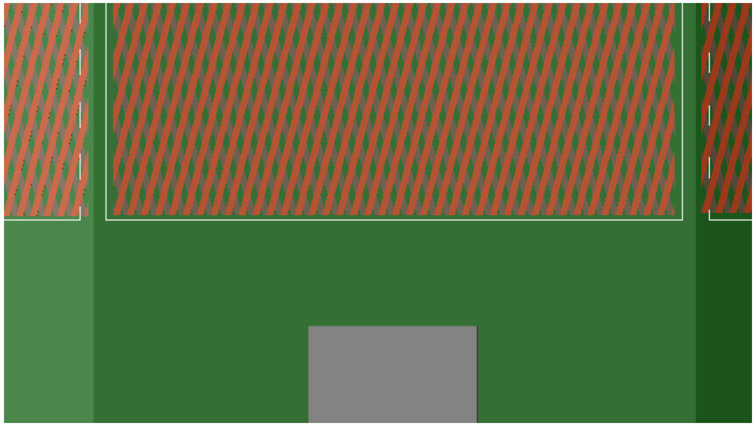


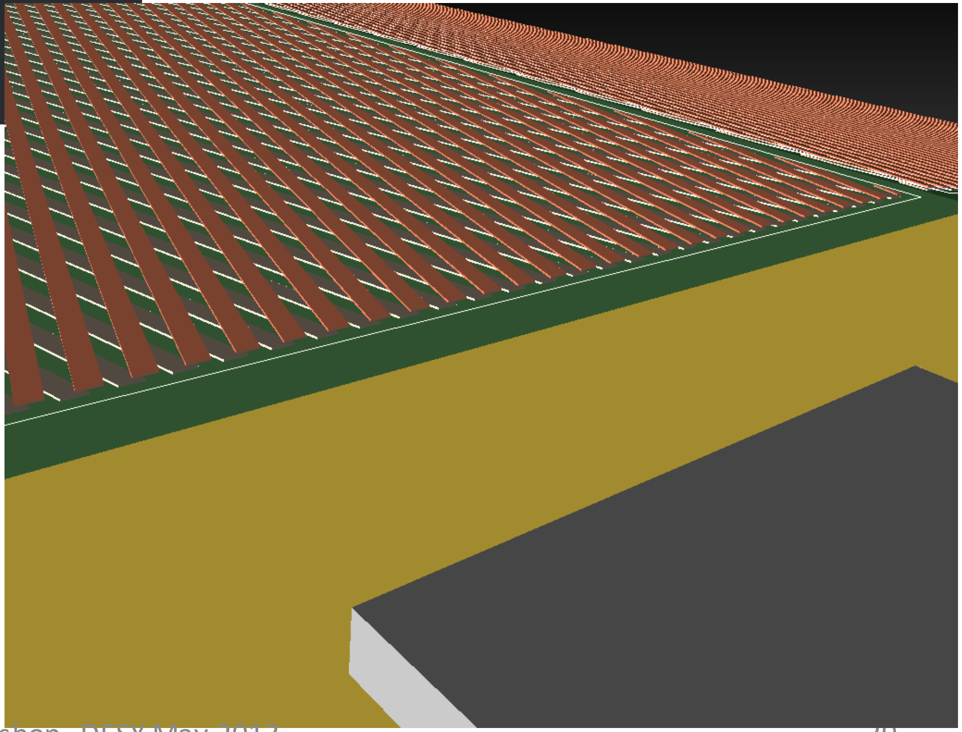


Crossed strip readout structure



5mm and 2mm spacer frame thickness





GEM in Range Stack

- Study hit precision requirements/anode patterns

- Need low mass chambers:

  Tensioning GEM foils – without thick walls/supports?

-? Build low mass ~1.9m x (5-10)cm chambers on a strongback…transfer to external tensioner – no “endcaps”?

- Readout – will start with SRS (RD51) with VMM2 FE.

- STATUS: Developing solution concepts…the simulation to test design and identify issues…

Summary

- GEM (double) for DHCAL proceeding to large chamber assembly and testing.

- THGEM variations tested in beam – options with good characteristics for DHCAL application.

- Exploring use of (triple)GEM for rare-K^+ decay experiment